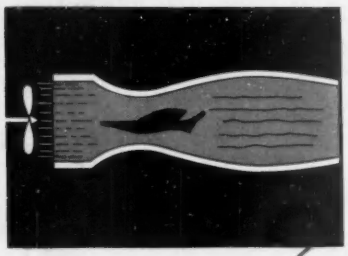
Control ENGINEERING

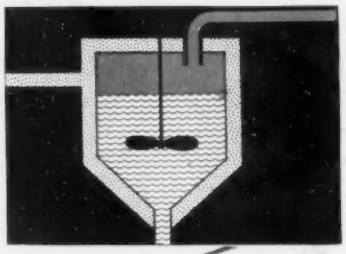
INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

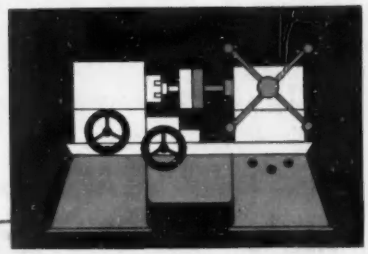
A McGRAW-HILL PUBLICATION

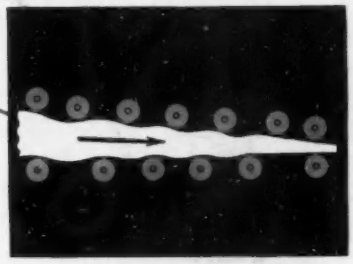
TWO DOLLARS

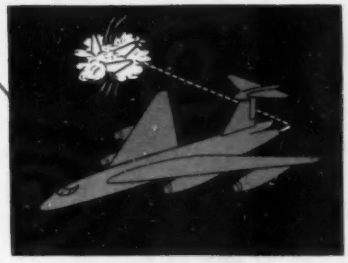
SEPTEMBER 1957

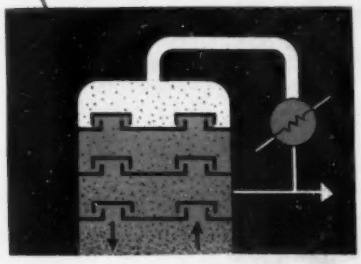


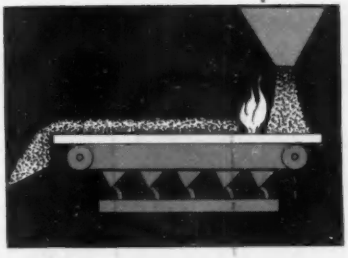


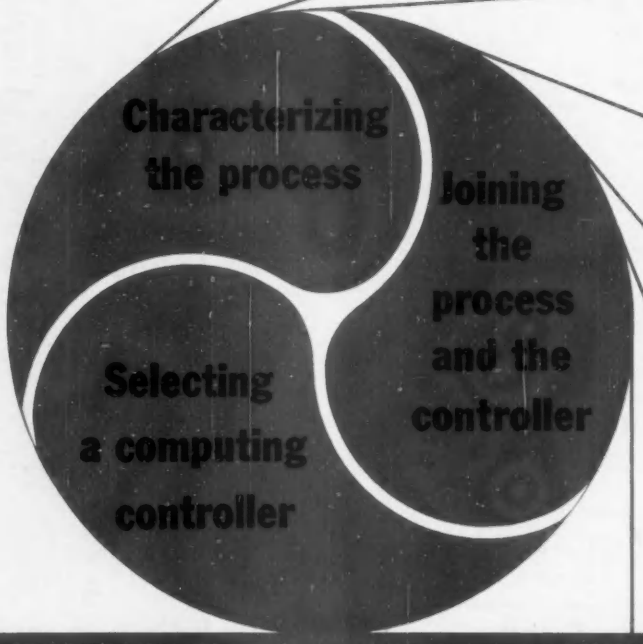








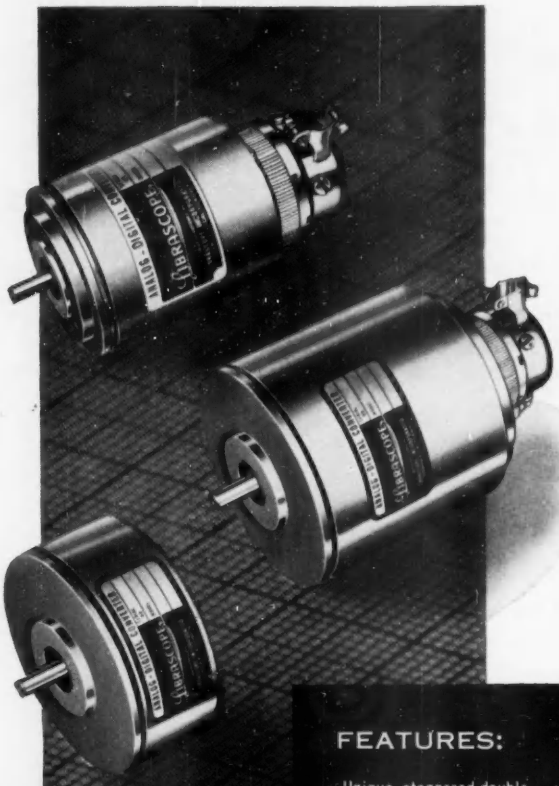




Computing Control

Flexibility in Application
Versatility in design...

packaged analog-digital converters



Shaft Position to Digital Converters features reliability, long life, non-ambiguity and speed makes these converters ideal for computers or data handling systems where serial read-out is preferred. Librascope converters transmit information at almost any rate desired up to 1 mc and in some cases above, and may be multiple time-shared, holding extra circuitry to a minimum. All units quickly adjustable, syncro-mounted. Available in Binary, Gray code or Binary decimal code as shown in chart below. Special units may be designed to your order.

Write for catalog information.

FEATURES:

- Unique, staggered double brush pick-off system.
- Reads out serially into relays or single or multiple scan matrices.
- Analog-digital or digital-analog operation.
- May be time-shared.
- Syncro-mounted.
- Associated circuitry can be designed to fit your data-handling problems.

CODE	MODEL*	RESOLUTION PER INPUT SHAFT REV.	RESOLUTION OVER FULL RANGE	DIMENSIONS DIAMETER X LENGTH
BINARY	7 digit	128	1 part in 128	2" x 2 49/64"
	13 digit	128	1 part in 8192	2" x 3 19/32"
	17 digit	128	1 part in 131,072	2" x 4 13/16"
	19 digit	128	1 part in 524,288	2" x 4 13/16"
BINARY CODED DECIMAL	0-2000	200	1 part in 2000	3 1/16" x 4 27/32"
	0-3600	200	1 part in 3600	3 1/16" x 4 27/32"
	0-20,000	200	1 part in 20,000	3 1/16" x 4 27/32"
	0-36,000	200	1 part in 36,000	3 1/16" x 6 3/8"
GRAY	8	256	1 part in 256	3 1/16" x 1 11/16"

*SPECIAL UNITS AVAILABLE

Precision gearing
Shaft Speed: 120 rpm continuous
Operating temp: −55° C to +75° C
Shock and Vibration: up to 15 G, 5 to 500 cps.

Life Expectancy: Function of lead current. For 13 digit unit @ 2 ma. per brush, life approx. 5×10^8 breaks or makes at approx. 120 rpm.

Engineers, physicists and mathematicians interested in challenging California careers, contact Mac McKeague, Personnel Director.

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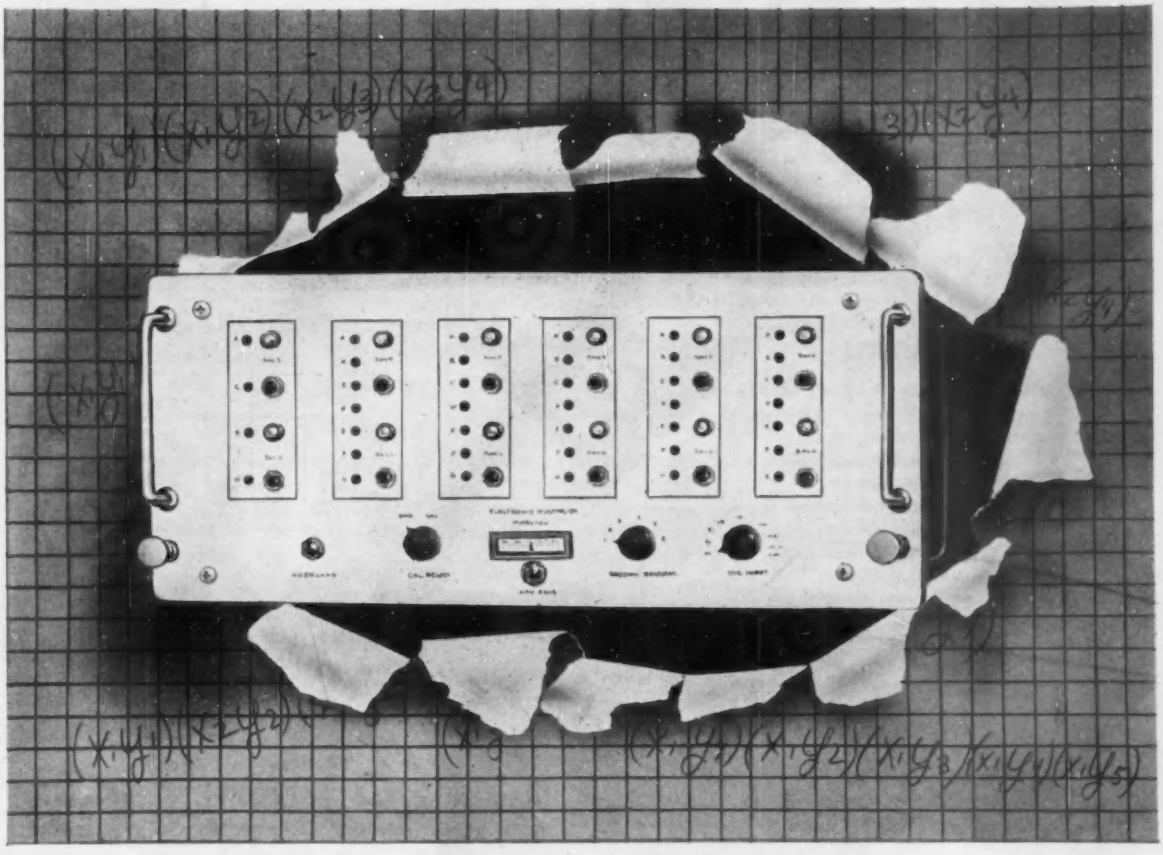

the first real advance in electronic multipliers

New GEDA M-160 permits custom-packaging of timer and output sections

How long have you wished for an electronic multiplier that would allow you to package timer and output sections at will—easily and accurately—to suit the needs of different computing problems? Well, wish no more, for here it is—the new GEDA M-160.

With the GEDA M-160, you can package any combination of *six* sections—timer or output—in a *single* module. Depending upon the requirements of the problem, you can obtain five products of one independent variable—four products involving two independent variables—or three products involving three independent variables. And, because output sections need not be matched to timer sections, you can interchange them at will with no sacrifice in accuracy.

Conservatively speaking, accuracy of the GEDA M-160 is 0.02% of full scale—phase shift at 100 cycles is within 0.5 degrees—and noise output is substantially less than that of conventional electronic multipliers.

The new GEDA M-160 Custom-Packaged Electronic Multiplier is one more of the advanced-design and engineering features which make the GEDA A-14 Series the most accurate and flexible analog computers ever available. Get the complete GEDA A-14 story today. Write: Goodyear Aircraft Corporation, Dept. 913GI, Akron 15, Ohio.

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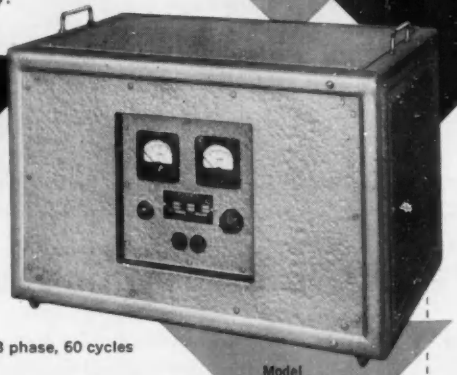
Regulation ±½%

IMMEDIATE DELIVERY!

DIMENSIONS: 26½" L x 17" D x 17" H.



Model MR2432-100XA

Additional Specifications:

Ripple: 1% RMS

AC Input: 208, 230 or 460V ±10%, 3 phase, 60 cycles

Weight: 230 lbs.

MODEL NO. MR917-100XA—also available: specifications same as above except output of 9—17 volts DC.

When you require a power supply, SPECIFY PERKIN, for a wider range of standard models and immediate delivery from stock.

Wire factory collect for prices. For a prompt reply on your application, write factory on your letterhead or contact local representatives listed below.

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28 Volt Models

Model	Volts	Amps	Reg.	AC Input (60 cps)	Ripple rms
28-5VFM	0-32 V	5	15-20% (24-32V range)	115 V 1 phase	2%
28-10WX	24-32 V	10	±½%	100-125 V 1 phase	1%
MR532-15A	2-36V	15	±½%	105-125V 1 phase	1%
28-15VFM	0-32 V	15	15-20% (24-32V range)	115 V 1 phase	5%
M60V	0-32V	25	±1%	115V 1 phase	1%
MR1040-30A	5-40V	30	±1%	100-130V 1 phase	1%
28-30WXM	24-32V	30	±½%	100-125V 1 phase	1%
28-50WX	24-32 V ±10%	50	±½%	230 V* 3 phase	1%
MR2432-100XA	24-32V	100	±½%	208/230V* 3 phase	1%
MR2432-200	24-32 V	200	±½%	208/230V* 3 phase	1%
MR2432-300	24-32 V	300	±½%	208/230V* 3 phase	1%
MR2432-500	24-32 V	500	±½%	208/230V* 3 phase	1%

*±10%. Also available in 460 V ±10% AC input. Will be supplied with 230 V input unless otherwise specified.

6, 12, 115 Volt Models

	Model	Volts	Amps	Reg.	AC Input (60 cps)	Ripple rms
6 Volt	6-5WX	6 ±10%	5	±1%	95-130 V 1 phase	1%
6 Volt	6-15WX	6 ±10%	15	±1%	95-130 V 1 phase	1%
6 Volt	6-40WX	6 ±10%	40	±1%	95-130 V 1 phase	1%
12 Volt	12-15WX	12 ±10%	15	±1%	95-130 V 1 phase	1%
115 Volt	115-5WX	115 ±10%	5	±½%	95-130 V 1 phase	1%
115 Volt	MR15125-5	15-125	5	±1%†	95-130 V 1 phase	1%††
115 Volt	G125-25**	115-125	25	±1½-4%	230/460 V 3 phase	5%

**Germanium Rectifier Unit ††Increases to 4% @ 15V.
†Increases to 2% @ 15V.

PERKIN POWER SUPPLIES

Control ENGINEERING

SEPTEMBER 1957 VOL. 4 NO. 9

Published for engineers and technical management men who are responsible for the design, application, and test of instrumentation and automatic control systems

126 **IMPROVED PERFORMANCE: The Computing-Control Goal**
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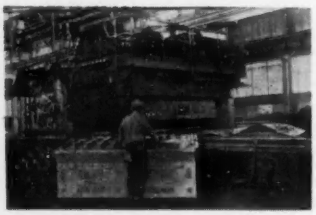

The contents page is one of the last made up in any issue, and it is here that we have a chance to rectify any plans gone awry. That's why this photo of Alcoa's 150-in. plate leveler is here. Naturally, we wanted it where it belongs—with the computing-control-applied article on page 141, but even with the best efforts of GE and Alcoa the photo came in too late. Art director Jack Gordon delayed layout to the last minute and then went ahead sans photo. You guessed it: it arrived in the mails the next morning, just a shade too late to reverse the go-ahead decision.

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ADVERTISING INDEX 354

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Model 1167 Pot Assembly slips out for easy access to components. Note independent clutches and fuses for each pot.

This advanced EASE SERVO SYSTEM...*

Sets pots to the nearest turn of wire in less than three seconds

The new EASE* 1100 Series servo-set potentiometer system permits automatic adjustment of coefficient pots to a typical accuracy of ±0.008% in less than 3 seconds average time. There are no dials to adjust, no meters to read, and almost no chance for error with the simple push-button selectors.

Heart of the system is a superior clutch design (patent applied for), the result of two years' field experience with servo-set pots. The new system uses no-drag clutches that disengage completely after setting, act independently of each other, and have an almost unlimited operational life. Tests show that these clutches far outlast the pots.

The Model 1166 pot system is an integral part of the EASE* DO/IT (Digital Output/Input Translator), which programs coefficients from punched tape and automatically operates and checks the 1100 Series computer.

Model 1166 servo-set pot system is another reason why the new Beckman/EASE* 1100 Series is rapidly assuming leadership of the analog computer field. For complete information on the computer and its components, please write Dept. L-9.

SPECIFICATIONS

Model 1166 Servo-Set Pot System

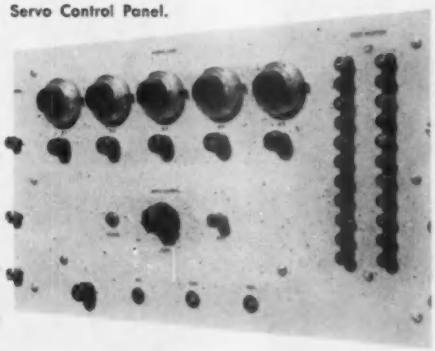
FRAME: 18" x 18" x 26". Mounts up to 10 Model 1167 Pot Assemblies (10 pots each). Includes two servo motors.

SERVO CONTROL PANEL: Contains Coefficient Selector; "Slew", "Null", and "Release" Controls; and five ungrounded manual pots.

POTENTIOMETERS:
100 Type A Helipots
Resistance: 50K ±5%
Resolution: 0.008%
Life: Exceeds 2,000,000 shaft revolutions

SERVO: Accuracy of Pot Setting: ±0.008% typical, ±0.016% maximum (within 2 turns of wire). Setting Time: Less than 3 seconds average; 5.2 seconds maximum, including release time.

Servo Control Panel.



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J. G. ZIEGLER, Pacific Coast Sales Engineer, a member of the Taylor Team of Instrumentation Scientists, is known internationally in his field. Together, the well-known team of Ziegler and Nichols have collaborated on such published papers as "Optimum Setting for Automatic Controllers," "Industrial Process Control," "Dynamic Accuracy in Temperature Measurement," "Valve Characteristics and Process Control," and many others.

N. B. NICHOLS, Chief Engineer, Taylor Instrument Companies, also has an international reputation as an instrumentation scientist. He was called to MIT during the war to work in the servomechanisms laboratory and later as group leader of the fire control division of the radiation laboratory. He edited a book on servomechanisms, and along with John Ziegler has authored a number of papers on the science of process control.

Bring your problems to these top

GEORGE E. HOWARD, Manager of the important Application Engineering Department of Taylor Instrument Companies, has had over 20 years experience in the design and application of engineered control systems, specializing in the Chemical, Petroleum and Textile Industries. During World War II Mr. Howard trained Government personnel on instrument operation and maintenance at the Government's Oak Ridge Atomic Energy Plant where Taylor was the prime contractor on instrumentation.

RICHARD N. POND, Vice President of the Instrument Society of America and a member of the Executive Board, has served the society in a variety of capacities since he first became active in the St. Louis chapter in 1946. He was secretary, and later chairman, of the committee on Instrumentation for Production Processing. He is a Divisional Sales Manager for his company, specializing in Oil Refining, Petrochemicals, Brewing, Power, Rubber and Plastics.

WE'RE FIELDING our first team at the ISA Show in Cleveland. There will be 27 top Taylormen there—the 4 shown and 23 listed below. We're proud of the ability and experience of this team.

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These men are typical of the world-wide Taylor sales and engineering organization that stands ready to help you with your instrumentation problems. Taylor Instrument Companies, Rochester 1, N.Y., and Toronto, Canada.

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TYPE 340

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Recent trends toward electrical control loops have created a need for final control elements capable of utilizing their greater sensitivity and speed. Fisher Electro-Hydraulic Operators are self-contained, electrically operated valve actuators, ideal for use in such control loops. They produce high performance without the use of electronic amplification, utilizing only a simple DC electrical circuit to control the hydraulic pilot. The pilot systems incorporate no close fitting parts, but use simple nozzle-flapper combinations to control hydraulic pressure.

Two sizes are available. To handle the most demanding control jobs Type 350 has a maximum stem thrust of 2000 pounds and is available for use on valve sizes ½″ to 16″ with strokes from ½″ to 3″. Type 340 is designed for the average control job. It has a maximum stem thrust of 600 pounds and is available for use on valve sizes ½″ to 4″ with strokes from 7/16″ to 1½″.

Rugged, simple design plus accurate, dependable performance, make the FISHER Electro-Hydraulic Operators the outstanding electric final control elements available.

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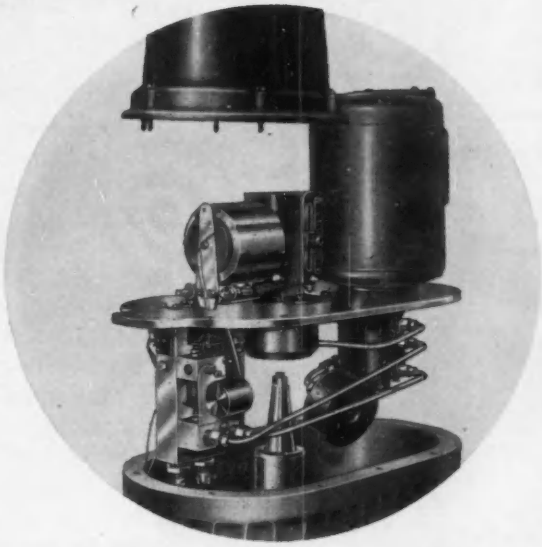
HYDRAULIC OPERATORS

TYPE 350



TYPE 340

- Adaptable to all DC output signals
- Requires only zero and travel adjustment (both readily accessible)
- Stroking range from 7/16" to 1½"
- Stroking speed 0.1"/sec.
- Resolution sensitivity—0.2% of input range
- Maximum stem thrust 600 pounds
- Operates on simple DC—no electronic amplification
- Valve sizes from ½" to 4"

TYPE 350

- Adaptable to all DC output signals
- Requires only zero and travel adjustment (both readily accessible)
- Stroking range from ½" to 3"
- Stroking speed 0.37"/sec.
- Resolution sensitivity—Better than 0.05% of input range
- Maximum stem thrust 2000 pounds
- Operates on simple DC—no electronic amplification

Valve sizes from ½" to 16"

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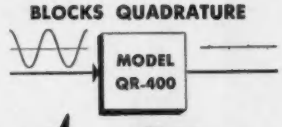
PASSES SIGNAL

BLOCKS QUADRATURE



MODEL QR-400

SPECIFICATIONS

- **Quadrature attenuation: 40 db min**
- **In-phase attenuation: 6 db max**
- **Maximum signal: 8 volts rms**
- **Maximum noise: 10 millivolts rms**
- **Circuit: interstage of either electron tube or transistor voltage amplifier**
- **Temperature range: −55 to +100 Centigrade**
- **Dimensions: 1½" x 1½" x 1½"**
- **Package: potted in epoxy resin hermetically sealed in metal case**

Also Model QR-60 for 60 cps applications

For complete specifications, write for

TECHNICAL BULLETIN 1557

FEEDBACK CONTROLS
INCORPORATED

Dept. CE
899 Main Street
Waltham 54, Mass.

SHOPTALK

computing-control, COMPUTING-CONTROL

This is how the technique looks to the CtE staff after months of work on the present issue. And we bet you feel the same way after you've read it. As you may know by now, we intended the feature section to consist of an integrated series of articles on the design and application of computing-control systems. But we never expected there'd be so much supplementary material to back up the features and give us a truly themed issue. Here are just a few examples of timely stories CtE's staff gathered for this issue:

What's New (starting on page 26), carries articles on: "Digital Computers Earn Their Wings"—a comprehensive coverage of who's doing what in the airborne digital computer field; "Largest Steerable Radio Telescope" . . . positioned to 12 min of arc by computing-controlled servo system—a brand new development in England; "British Study Computing Control"—which points out that the status in the U. S. and England is about on a par; and "New Digital Computer for Process Control"—the details of the Ramo-Wooldridge computing-controller program.

Another section, *Industry's Pulse*, poses the question, "What's the Market for Computing-Control?" and shows that the status of the market fluctuates, depending on who you're talking to. Of course, this doesn't mean the technology itself isn't firming up; it is. But no composite market figure exists; those in *Pulse* are CtE-surveyed.

Also affected by our all-pervasive theme is *Control Personality*, (page 25), which this month spotlights John Salzer, ardent disciple of computing-control. He also happens to be the author of one of the articles in our 79-page feature section. It seems that wherever you start reading, you'll meet our theme. Well, we planned it that way. Have fun.

How About Next Year?

The major force that keeps us on the straight and narrow is reader commentary. Let us know what you think of this issue (and others to come, too). You might also send along your ideas on what you think we should do about September 1958. Believe it or not, that problem comes up for us in a month or two, because it takes a long time to generate a good integrated issue. Your suggestions will help us make a decision.

Derek Gets Into Gear

In an amazingly short time, Derek Barlow (European editor of CtE) has started a steady stream of good material flowing across the Atlantic. Chances are you've already noticed his items sprinkled throughout *What's New*, but keep a lookout for his first major feature, "A First-Hand Report on Control in British Steel", in the next issue of CtE.

NEWEST SUCCESS STORY IN THE

recti/riter

LINE . . .

Model 301
ALL-TRANSISTOR DC AMPLIFIER
for millivolt recording!

Basic Unit Price $315.00

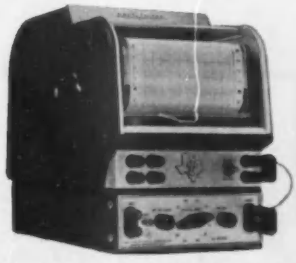
Now, the range of the reliable time-saving "recti/riters," rectilinear galvanometric recorders, is extended to millivolt sensitivities by the addition of the new Model 301 DC Amplifier. Record 10 millivolts to 100 volts by direct attachment to the "recti/riter" or any galvanometric recorder having input characteristics of 1 ma input and approximately 1500 ohms resistance.

A *true* multirange recording voltmeter, the Model 301 Amplifier features the use of transistors throughout instead of vacuum tubes, and an electronic system of modulation instead of noisy, troublesome mechanical choppers.

The compact (2½" x 7½" x 10") Model 301 provides DC amplification with AC stability—covers range from 10 mv DC full scale to 100 volts in 12-step selection—transistors eliminate bulk, give long life and rapid stabilization—either AC or battery power operates instrument without modification or attachments—available in horizontal or vertical form for optional desk, panel, or integral recorder mounting.

For further detailed information, write for Bulletin R-503, or contact your TI representative.

INDUSTRIAL OR MULTIPLE USE—two horizontal DC amplifiers in standard 19-inch relay rack with DUAL "recti/riter." Seven vertical amplifiers may be mounted across the rack in a similar manner.



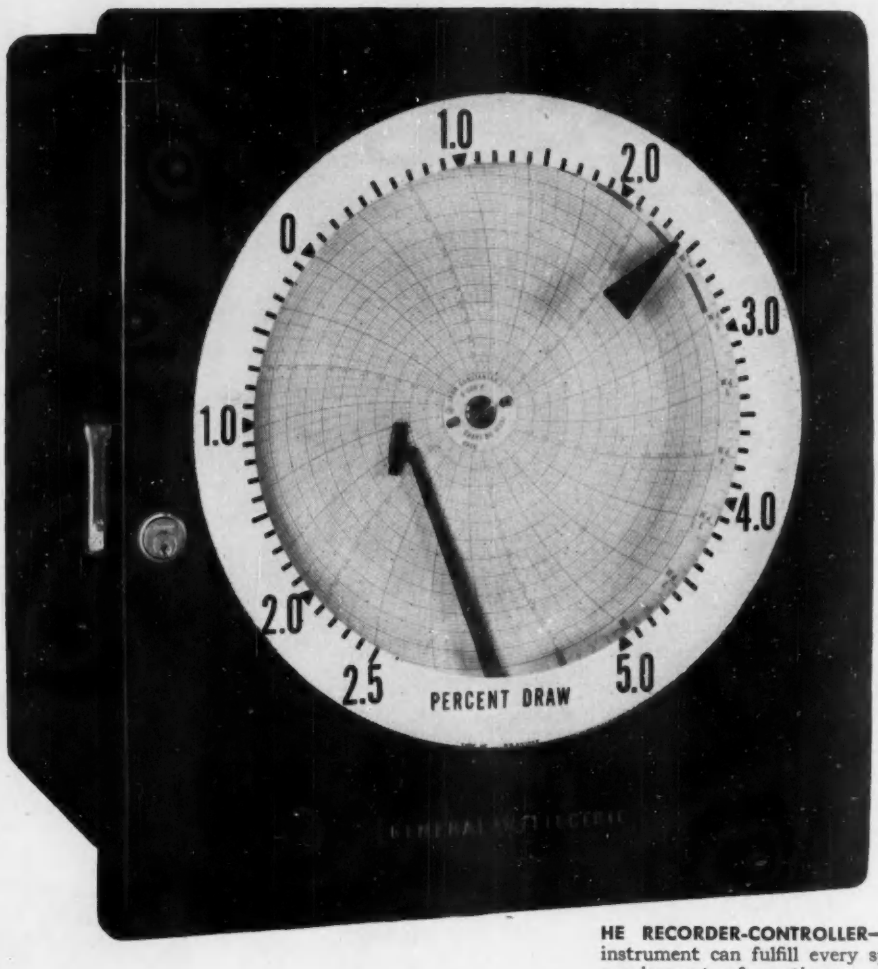
PORTABLE USE — Amplifier fits rack attached to SINGLE "recti/riter" to form integral easy-to-carry unit.

TEXAS INSTRUMENTS
INCORPORATED
INDUSTRIAL INSTRUMENTATION DIVISION
3609 BUFFALO SPEEDWAY • HOUSTON, TEXAS • CABLE: HOULAB
Formerly: HOUSTON TECHNICAL LABORATORIES

1216

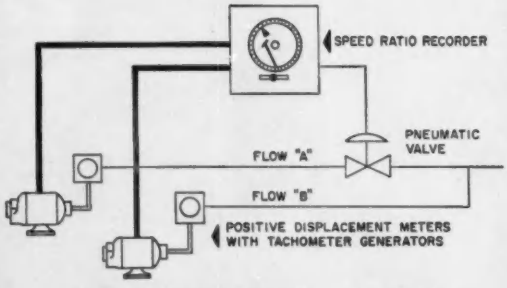
NOW, Control Speed to ±0.1%

GENERAL ELECTRIC'S ROUND-CHART RECORDER GIVES YOU

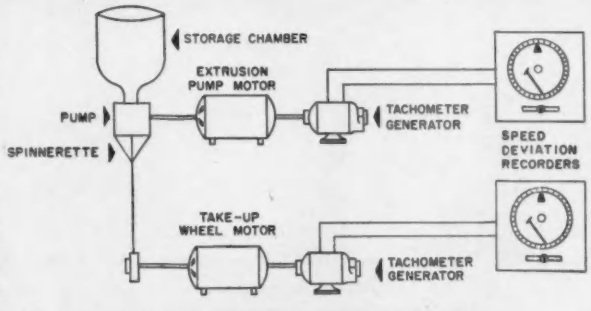


HE RECORDER-CONTROLLER—Versions of this instrument can fulfill every speed measurement requirement of continuous process industries.

HERE'S HOW TO INSTALL GENERAL ELECTRIC'S ROUND-CHART



BLENDING SYSTEM — RATIO



FIBER SPINNING — DEVIATION

with a Low-cost D-c System

FREQUENCY-SYSTEM ACCURACY AT MUCH LESS COST

NOW . . . General Electric offers a d-c speed measurement system that provides the high accuracy usually associated only with a frequency type measuring system—at much less cost!

ACCURACY TO ±0.1%—General Electric's speed measurement system—a combination of one or more Type HE Recorder-Controllers and one or more Type 5BC46 Tachometer Generators—provides accuracy as high as ±0.1% for measurement of speed variables.

MAXIMUM SYSTEM ACCURACY—The extremely high accuracy of General Electric's speed measurement system is possible because of the HE Recorder-tachometer generator combination. General Electric's tachometer generator (Type 5BC46) is a vital component of the precision system. And—for maximum accuracy in continuous process applications—the General Electric tachometer generator should always be used with the HE Recorder-Controller.

SIX SPEED VARIABLES—Continuous process manufacturers can fulfill every speed measurement requirement with the General Electric system. This broad application is possible because the General Electric speed measurement system will measure six speed variables. They are: (1) direct speed (2) speed differential (3) speed ratio (4) speed deviation (5) expanded-scale precision speed, and (6) time in process.

MEASURES OTHER VARIABLES—In addition to providing accurate speed measurement, the General Electric HE Recorder also measures, records, and controls: temperature, pH (acidity), power, volts, amps, viscosity, tension, and gas analysis.

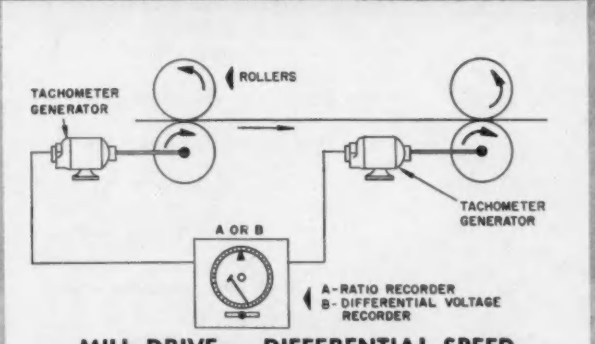
For further information, write to Section 587-9, General Electric Company, Schenectady 5, N. Y., or contact your nearest General Electric Apparatus Sales Office.

GENERAL ELECTRIC'S HE RECORDER OFFERS THESE BENEFITS

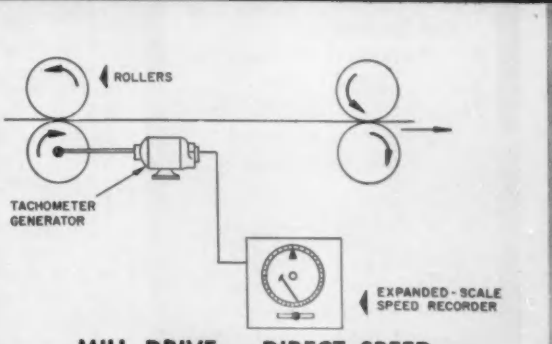
- **high production and reduction of scrap because of accurate measurement**
- **reduced maintenance and reduced operating expense**
- **sustained accuracy and precision measurement**
- **continuous, dependable operation—even at 125F ambient**
- **increased chart readability and simplified chart changing**
- **continuous standardization, at no additional cost**

GENERAL ELECTRIC

RECORDER FOR ACCURATE MEASUREMENT OF SPEED VARIABLES



MILL DRIVE — DIFFERENTIAL SPEED



MILL DRIVE — DIRECT SPEED

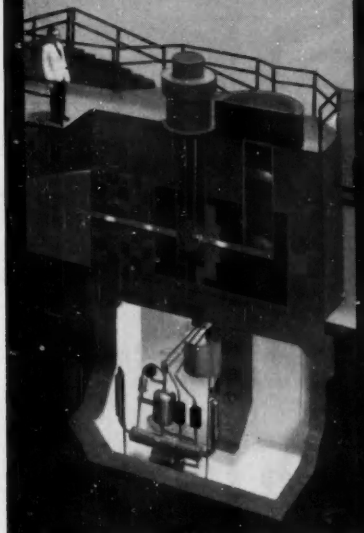
Do you think of pressure transducers?

AI

ATOMICS INTERNATIONAL

DIVISION OF NORTH AMERICAN AVIATION, INC.

does... and uses Statham pressure transducers as part of the control instrumentation in the construction of its nuclear reactors which open entirely new fields in industrial research and development by providing an on-the-spot source of high-energy gamma rays and neutrons.



WHEN THE NEED IS TO KNOW...FOR SURE SPECIFY STATHAM

Accelerometers
Pressure Transducers
Load Cells

Catalog, complete with prices, available upon request.

Statham
LABORATORIES
LOS ANGELES 64, CALIFORNIA

FEEDBACK

Check your memory

To the Editor—

I would appreciate very much your letting me know if you have published works on the utilization of mechanical and electronic data processing in business administration and research operations.

Paul Gothier
Liege, Belgium

We sure have. Here is a list:

1. "How Input/Output Affects Performance", J. Gibbons, July '57.

2. "How the Four-Tape Sorter Simplifies Storage", R. G. Canning, Feb. '57.

3. "What to Consider When You Buy Electronic Data Processing", C. E. Faulkner, Nov. '56.

4. "Programming Business-Data Processors", G. W. Hopper, Oct. '56.

5. "Controlling a Business Process", R. G. Canning, Sept. '56.

6. "Processing Business Data", C. W. Adams, June '56.

7. "Data Processing and Inventory Control", E. D. Lucas, Sept. '55.

Items 1, 2, 4, and 6 are available at 25 cents per reprint. Several others will appear in a special bound volume of 14 reprints covering the application of digital equipment and devices. The volume will be available about October of this year at a single-copy price of $3.00. Ed.

For the record, tape unit searches

To the Editor—

Mr. James Gibbons' article, "How Input/Output Units Affect Data-Processor Performance," published in the July 1957 issue of Control Engineering, was very interesting. However, I would like to make several additions and corrections.

The magnetic tape unit comparison, Table IV, did not mention the ability to search—an extremely important point in any tape system. Both the ALWAC III-E and the ALWAC 800 can search in different modes.

In the ALWAC III-E two searching modes are available with the search keys in their respective comparing registers:

1. Compared with the first word of tape block (record) for greater than or equal to.

2. Compared with the last four bits (hexadecimal digit) of the first word of equality. Note that 15 of the tape units may be searching for 15 different numbers simultaneously as well as reading or writing a 16th.

In the ALWAC 800 three searching modes are available with the search keys in the A register and the sign position considered as the least significant:

1. File maintenance (search on inequality)—compared with first word for greater than or equal to.

2. Table lookup (search on equality)—compared with the first word of block that is greater than and then tape reversed and first word of block compared for less than or equal to.

3. Classification code (search on flag)—each nonzero digit of the search key compared with the corresponding digit of the second word of the block.

The DATATRON can also search for preassigned block addresses. Corrections to Table IV are:

1. Maximum number of units on-line for ALWAC III-E is 16, and

2. Rewind speed is over 500 in./sec on both ALWAC computers.

The following are additions and corrections for the remainder of the text:

1. The ALWAC III-E and ALWAC 800, as well as the DATATRON, use punched paper tape as input-output media; however, only the III-E and 800 are completely alphanumeric.

2. The ALWAC computers utilize IBM punched cards as input-output media.

3. The ALWAC computers can attach a high-speed printer (over 600 lines per minute). Note that the ALWAC III-E is the only medium-speed computer able to accomplish this.

4. The ALWAC computers may be completely buffered on input-output, allowing such operations as simultaneous reading and punching.

5. The control half of the ALWAC III-E card buffer plus the plugboard can do everything the Cardatron can do with one format band with the additional advantage of interchanging digits or fields.

It is hoped that the above information will prove of assistance to you. Thank you for your interesting article.

Andrew T. Fischer
ALWAC CORP.
New York City

News item stimulates query

To the Editor—

Will you please tell us where we can

TALK ABOUT MINIATURIZATION!

...Giannini has really hatched one this time.

almost spaceless... almost weightless

THE "ONE CUBIC INCH" PRESSURE TRANSDUCER —so small that 93 instruments won't quite cover this ad—packs king-sized performance in its 1"/side case.

Developed for the Vanguard Earth Satellite, this potentiometer output transducer provides a high level output proportional to absolute, differential or gage pressures to 50 psi. Resolution is better than 300 wires (0.33%) and weight is *less* than 3 oz.

* *For full details, please write for Data Sheet No. 451218, the "Cubic-Inch" Pressure Transducer.*

Giannini

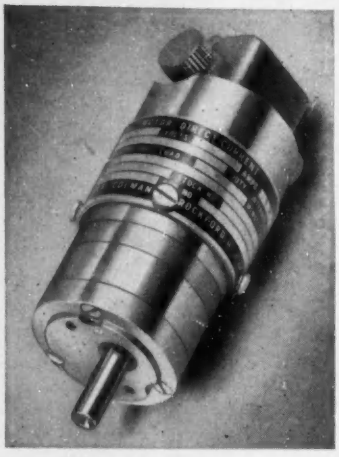
CHICAGO, ILL., 8 South Michigan Ave.
NEW YORK 1, N.Y., Empire State Bldg.
PASADENA, CALIF., 918 East Green St.

G. M. GIANNINI & CO., INC. • 918 EAST GREEN STREET • PASADENA, CALIFORNIA

BARBER COLMAN

Gearhead Motors

permanent magnet type with maximum torque output from 5 to 10 pound-inches



Here are permanent magnet gearhead motors that can be used as small actuators to drive switches, programming devices, camera mechanisms, autopilots, flight simulators, and for remote positioning in industrial automation. Ideally suited for variable speed requirements due to extremely stable characteristics over a wide range of supply voltage. The standard Barber-Colman BYLM motor with gearhead, as illustrated, is supplied with outputs up to 1/10 hp and speeds from 5,000 to 20,000 rpm less gearhead. Gear ratios for unit shown are available from 9.5 to 55,446/1. Maximum torque output from 5 to 10 pound-inches (other type gearheads available with outputs up to 500 pound-inches). Send for free technical data.

The complete line of Barber-Colman d-c motors

. . . includes both permanent magnet and split series types . . . in various mountings and speeds with outputs up to 1/10 hp. Ideally suited to power electro-mechanical actuators, switches, and programming devices. Also available with gearheads or blowers for special applications. Whatever your problem involving small d-c motors, let Barber-Colman Company engineers help you find the solution. Write for free Catalog F-4344-4.

Barber-Colman Company

Dept. U, 1848 Rock Street, Rockford, Illinois

FEEDBACK

obtain information and literature describing the operation of the titromatic analyzer shown on page 24 of the July '57 issue of CONTROL ENGINEERING magazine.

A. C. Page
American Potash & Chemical Corp.
Henderson, Nev.

Contact the manufacturer, Electronic Instruments, Ltd, Richmond, Surrey, England, for full information on the titromatic analyzer. Ed.

Where's the switch?

TO THE EDITOR—

We are endeavoring to contact a manufacturer of a rotary switch having two poles and up to 50 ways. The switch should be capable of rotating at up to 100 rpm.

We believe that you have at some time shown such a switch in your columns, and hope that you will be able to put us in touch with such a manufacturer.

R. C. Lisle
Bonochord, Ltd.,
Bucks, England

Here . . .

TO THE EDITOR—

We are indeed pleased to confirm that we manufacture a wide variety of motor-driven sampling switches similar to the type requested. We can supply units having two or more poles and from 30 to 200 channels of information with or without integral drive motors and gear trains.

Robert Cushman
General Devices, Inc.,
Princeton, N. J.

. . . but not here, now

TO THE EDITOR—

Unfortunately, we do not manufacture such equipment. We have, however, manufactured some high-speed electronic switching which would sample many contacts at 60 cycles per second each. Although we have built some of this equipment, we are no longer supplying this, since it was found it was just too expensive for normal industrial application.

H. T. Sawyer
The Kybernetes Corp.,
Brooklyn, N. Y.

Terminology grab-bag

TO THE EDITOR—

Aperiodically I have to express a desire to encourage editors to improve technical communications by needling for new and better definitions.

Why don't you encourage a subdepartment of definition discussion within your "Letters to the Editor" section?

I enclose some notions along these lines.

1. Automation: Automatic programing and regulation of a process.
   A. Automatic programing: performing functional operations in a predetermined order, fashion, amount and duration.
   B. Automatic regulation: Varying functional operations to hold product quality constant in spite of variations in raw materials, processing equipment, and environmental conditions.
   C. Exceptions: Unfortunately, the word "automation" has been appropriated by the automatic materials-handling industry to embrace all new labor saving transport devices.
2. Information, intelligence, and data-processing systems.

Man is constantly measuring, deciding about, and modifying the materials and forces of nature. To do this effectively requires clerical processing of a tremendous volume of data, usually in the language of numbers, because arithmetic is perfectly regular, capable of relating very complex concepts, and can provide an infinity of subtle nuances.

The new automatic data computers so greatly extend man's clerical abilities as to open wholly new fields to man's control of his environment.

A. Data computer: A high speed automatic moron which combines memory, arithmetical ability, elementary logical, criterion-testing and decision-making, ability to translate between various data languages, plus the ability to check and indicate its own malfunctions.
B. Digital data: Information in the form of discrete bits that can be counted.
C. Analog data: Information in the form of continuous size that can be measured by a scaling comparison.

J. N. A. Hawkins
BJ Electronics
Santa Ana, Calif.

No comment. We publish Mr. Hawkins' suggested definitions because they may aid other readers. Perhaps Mr. Hawkins would profit by submitting his suggestions to ASA Committee C85, which is busily engaged in rounding up terminology that will combine the automatic-control terminology previously recommended by AIEE, IRE, and ASME. Strange, the tentative standard terms tabulated

on April 19 by ASA C85 for study do not include automation. Ed.

To a numerical controller, is an oil well just another machine tool?

To the Editor—

In the February 1957 issue of Control Engineering, under the Abstract section, on page 194, you published a review of the following report: "Numerical Control of Machine Tools" by the AIA-AMEC Numerical Control Sub-Committee, C. B. Perry and B. Gaiennie.

We would very much like to obtain a copy of this complete report, and would appreciate your furnishing us the necessary information to obtain such a copy.

J. K. McGee
Gray Tool Co.,
Houston, Tex.

As we told another reader earlier (Ct E, July, p. 12), the material mentioned in our February issue was an abbreviated version of the complete report, which received mention in a news item in our August issue. A limited number of these reports are available to interested persons through:

Miss Catherine M. Prentice
Aircraft Industries Association
610 Shoreham Building
Washington 5, D. C.

Dropped dots

To the Editor:

I would like to thank you for publishing my abstract of the Russian article on reducing nonlinear distortion (CtE, June 1957, p. 212).

However I would like to call your attention to a misprint in the equations. The dots denoting differentiation have been omitted from K, α and β. As a result the equations as they appear relate the variables instead of their derivatives. The equations for reducing nonlinear distortion should read:

$$\dot{K}\,\dot{\beta} = -\dot{\alpha}$$
$$\dot{\beta}\,\dot{\alpha} = -1$$

Michel Mamon
Brooklyn, N. Y.

What one word will do

To the Editor:

I am writing in regard to the article "Magnetic Springs for Accelerometers" by Mr. E. S. Shepard Sr. in the June 1957 issue of Control Engineering.

I feel that the the article is misleading as to what an accelerometer actually is. The article states, "For frequencies far enough above the natural resonant frequencies of the sprung mass, positioned displacement of the seismic mass relative to the frame of

THE MARK OF QUALITY

BARBER COLMAN

Small Motors

TYPE DYAZ

"We needed a dependable geared synchronous motor for accurate chart drive on our Monitorecord"

Sheffield Corporation, Dayton, Ohio

The new "Monitorecord" by Sheffield Corporation, Dayton, Ohio, times and records simultaneous and sequential operational events of automatic machines and devices. Capable of monitoring up to 14 separate operations simultaneously, this instrument provides a split-second recording of each operation as the equipment starts, runs, and stops. Scribed time lines appear on a strip chart. To accurately drive this chart, Sheffield Corporation selected the Barber-Colman DYAZ geared synchronous motor. "Plus" features of this geared motor include double-supported gear shafts with sintered bronze bearings . . . extra large oil wicks . . . helical pinion and gear in first step . . . heavy-duty gears and output shaft. If you have a design problem involving small motors, let Barber-Colman Company engineers help you solve it with the exact motor for the job.

FREE HELPFUL DATA SERVICE on the complete line of Barber-Colman small motors, which includes unidirectional, synchronous, and reversible motors up to 1/20 hp. With or without reduction gearing . . . open or enclosed types. Expert engineering service available. Write today, outline your problem, ask for free data sheets and Catalog F-4271, or see Sweet's Product Design File.

REVERSIBLE

SYNCHRONOUS

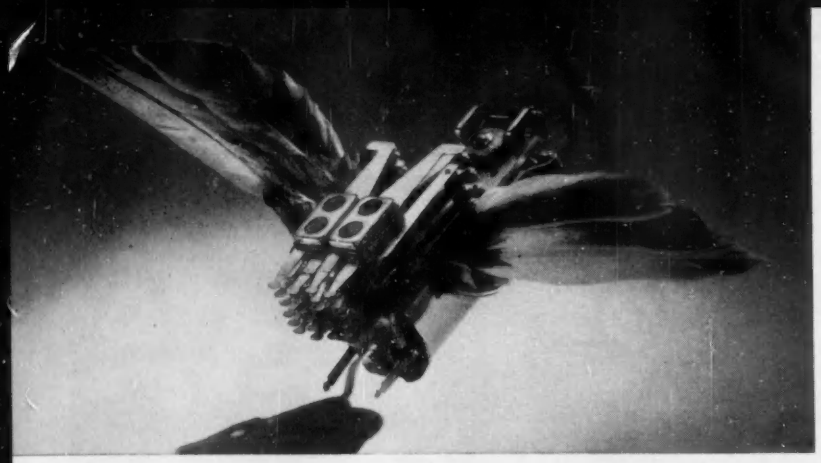
GEARED

UNIDIRECTIONAL

BARBER-COLMAN COMPANY

Dept. U, 1248 Rock Street, Rockford, Illinois

Small Motors • Automatic Controls • Industrial Instruments • Aircraft Controls
Electrical Components • Air Distribution Products • Overdoors and Operators
Molded Products • Metal Cutting Tools • Machine Tools • Textile Machinery



"Your prototype is arriving by air from PHILLIPS"

Phillips has the ready answer for controlling large numbers of circuits in its Type 2 relay. Available in countless variations, contact combinations and coil windings. Type 2 offers a large coil winding capacity. This permits single and double wound coils and the use of copper or aluminum slugs for time delay on pick-up and drop-out. Large contact capacity permits assemblies of 24 contacts on one relay in a variety of types. Choice of single or twin contacts using precious metals or snap action switches. Type 2 is built from standard precision parts with special features included to fill specific requirements.

If *any* relay problem has you up in the air, let the "man from PHILLIPS" help.

COIL CHARACTERISTICS:
Operating Voltage: up to 750 volts D. C. up to 440 volts A. C. 60 cycles.
Resistance: up to 50,000 ohms.
Single or double wound.
Operating Current: 0.001 amps. D. C. Minimum
Operating Time: 0.002 secs., minimum 0.400 secs., maximum

CONTACT ASSEMBLY:
All forms A through E
Single or double pileup.
Code #4 Palladium contacts, standard.
Other contacts available.

MOUNTING:
Two No. 8-32 tapped holes, standard.

VARIATIONS:
Plug-in mountings and terminals.
Slow-operate and slow-release coils.
Taper tab terminals.
Micrometer screw adjustment.
Microswitch contacts.
Metal enclosures.
Hermetically sealed.

HERMETIC SEALS, MULTI-CONTACT, POWER, HERMETICALLY SEALED RELAYS, ACTUATORS

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FEEDBACK

the accelerometer is directly proportional to acceleration of the frame." This relative position is actually an indication of displacement. An accelerometer must be operated below its resonant frequency instead of above.

C. F. Sanders
Waco, Tex.

Reader Sanders is right. The paragraph under "Theory of operation" on page 143 of the June issue should have read: "For frequencies far enough *below* the natural resonant frequency of the sprung mass, positional displacement of the seismic mass relative to the frame of the accelerometer is directly proportional to acceleration of the frame. The *highest* useful frequency is limited by the resonant frequency f_r, and, for any given f_r, by the damping between the seismic mass and the frame." Ed.

She is a smasher!

TO THE EDITOR:

On page 23 of your July issue there appears a photograph and a description of the Elliot Bros. stand at the recent British Instruments, Electronics & Automation Exhibition.

I think that it should be made clear that the young lady adding the human touch to this highly automatic equipment appeared there by permission of *Automation Progress*, Britain's automation journal. Billed as "Miss Automation", she attracted a great deal of interest.

E. G. Semler
Leonard Hill, Ltd.,
London, England

Our regrets. This was a detail that European Editor Barlow failed to cable. And she's a smasher, too. Ed.

Readers across the Pacific

TO THE EDITOR:

We are attempting to determine if information relating to certain direct-coupled transistor circuits has appeared in printed publications in Japan. These circuits are described in the December 1956 issue of CONTROL ENGINEERING.

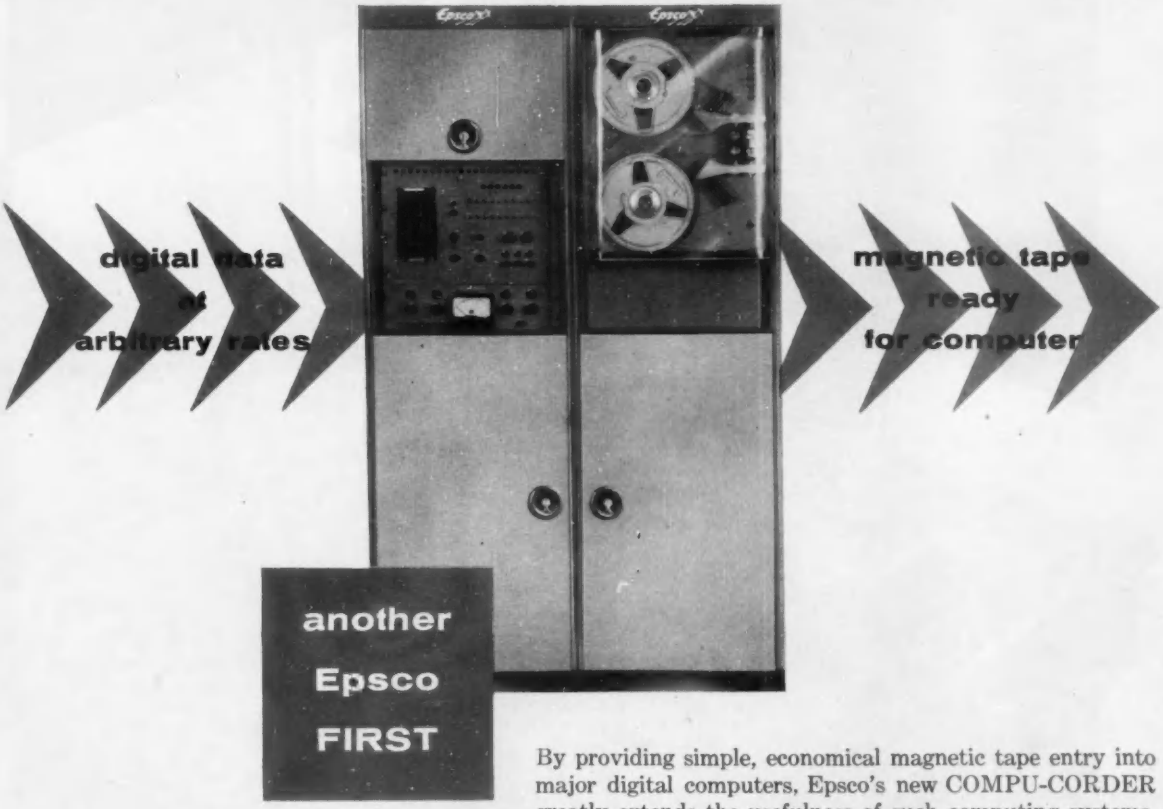
We would appreciate it if you could tell us if any copies of the December 1956 issue were sent to subscribers in Japan, and if you could give us a rough estimate of the number of copies sent.

Allen V. Hazeltine
Philco Corp.

According to our Circulation Dept., 272 copies of the December 1956 issue were mailed to control engineers in Japan. Ed.

NEW EPSCO COMPU-CORDER

FACILITATES COMPUTER ENTRY



By providing simple, economical magnetic tape entry into major digital computers, Epsco's new COMPU-CORDER greatly extends the usefulness of such computing systems.

An inexpensive, packaged system, the COMPU-CORDER receives and gathers asynchronous digital data from several external sources and combines them in any selected sequence together with manually inserted fixed data and internally generated record numbers.

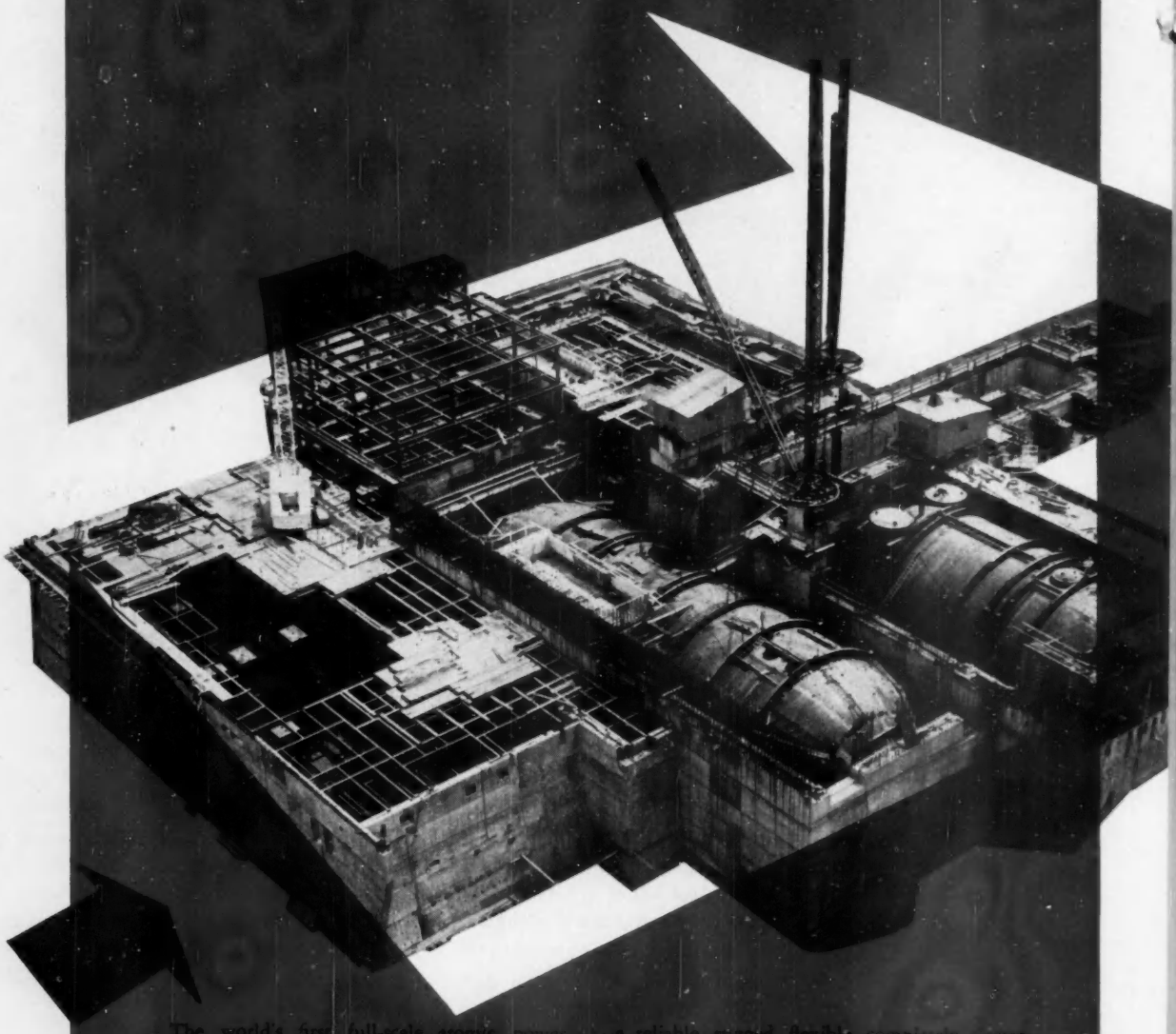
The COMPU-CORDER then records the combined digital record of information on magnetic tape in exact computer format. Complete flexibility of programming is provided allowing selection of gap length, tape format, and information sequence.

Internal magnetic storage permits peak data entry rates as high as 40,000 12-bit words/sec. Average data entry rates are limited only by the computer format selected and by the permissible tape packing density. Write for further details.

Epsco -First in Data Control

Epsco, Incorporated, 588 Commonwealth Ave., Boston 15, Mass. 108-03 Queens Blvd., Forest Hills 75, N.Y.
For service in the West: Epsco Service Corp. of California, 1722 Westwood Blvd., Los Angeles 24, California

pressure, flow, temperature

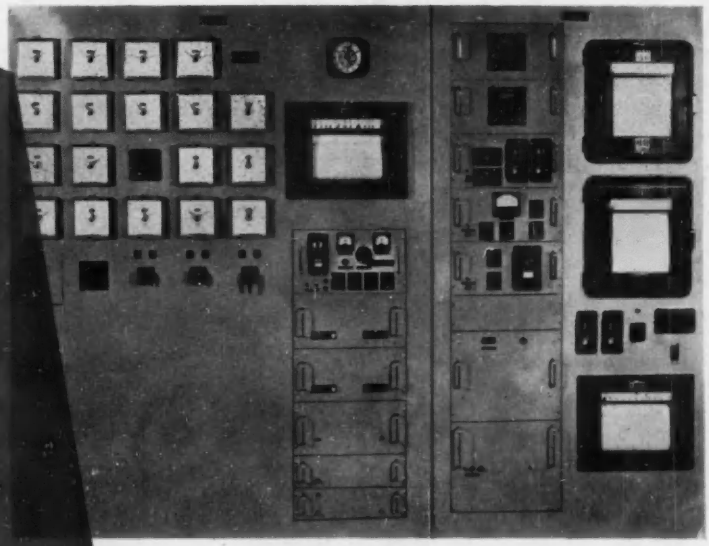


The world's first full-scale atomic power plant for civilian needs, utilizing a pressurized water reactor, will go into operation this year at Shippingport, Pennsylvania. It has been designed and constructed by Westinghouse Electric Corporation for the Atomic Energy Commission and is to be operated by Duquesne Light Company.

Norwood Controls' ELECTROSYN SYSTEM and other special Norwood instrumentation control the primary reactor plant in this history-making installation. ElectroSyn is a reliable, rugged, flexible, completely electromagnetic null-balance system designed for a wide variety of applications in the atomic, chemical processing and gas and petroleum refining and transmission fields. At PWR it measures, indicates and controls pressure, flow, level, temperature, etc.

A power reactor system demands the utmost in reliability and accuracy of its control instrumentation — which is one way of saying "ElectroSyn"

in PWR, FIRST U. S. full-scale atomic power station . . . controlled by ELECTROSYN SYSTEM



Norwood Controls' Power and Temperature Control Panel and Auxiliary Instrument Panel (at left) are the heart of the PWR reactor plant instrumentation and control system. Measurement, computation, auctioneering, alarm, and control functions are performed.

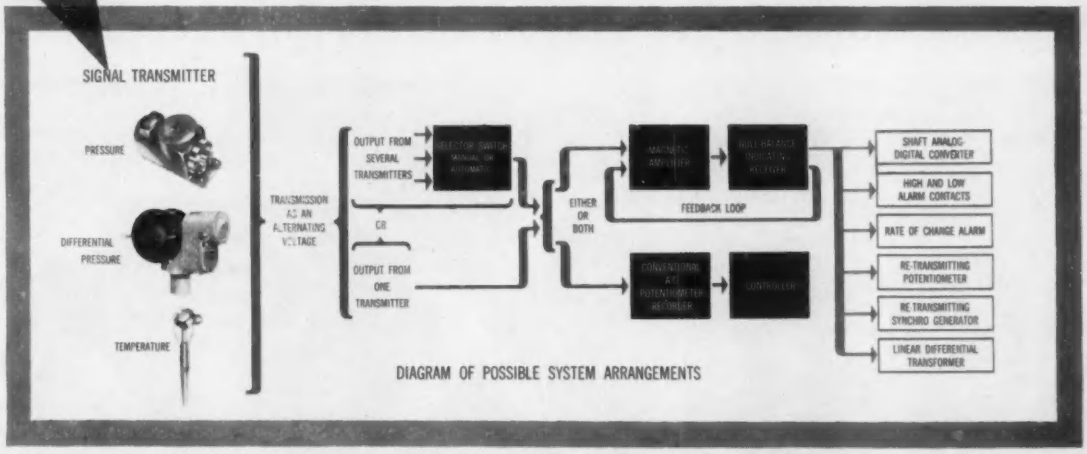


DIAGRAM OF POSSIBLE SYSTEM ARRANGEMENTS

Write for descriptive literature on "ELECTROSYN SYSTEMS"

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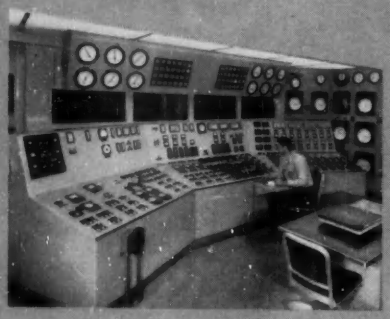
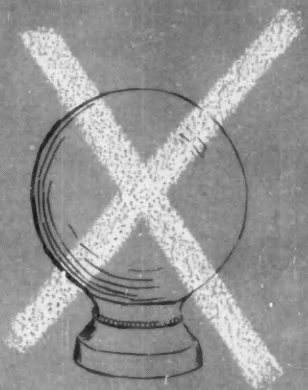
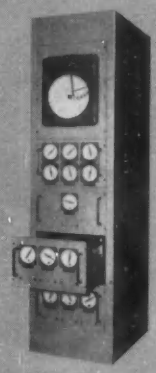


controlling





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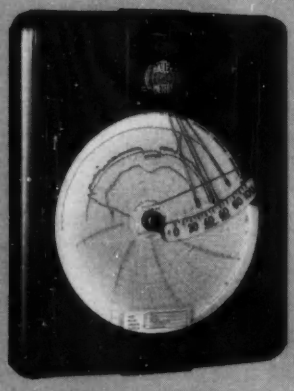

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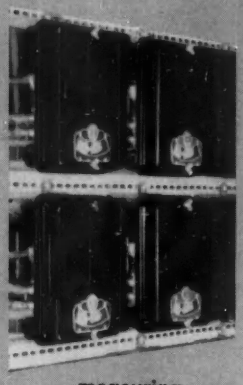
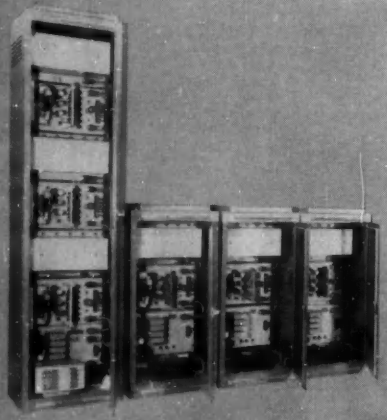
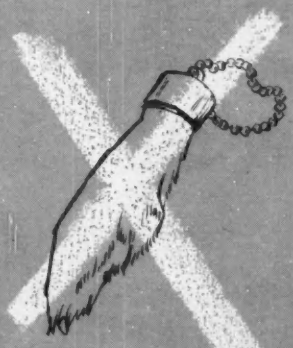


measuring



data logging



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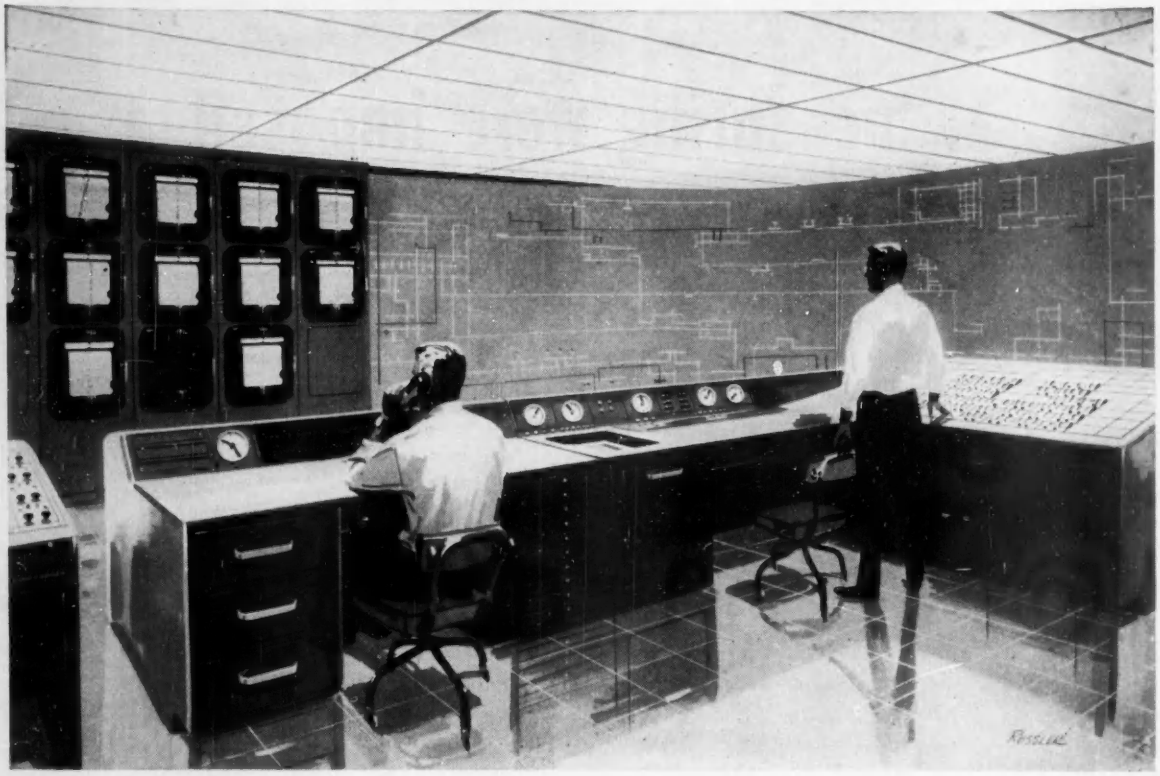

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New "Desired Generation" Computer to integrate with present Florida Power & Light Area Control

Written by J. F. Springman, Leeds & Northrup Co., for this advertisement

• Because so many industries are building plants in Florida, FP&L has taken bold steps to keep up with an astonishing load growth: generating capability has more than quadrupled since World War II. Not content with the addition of 800,000 kw in that period, FP&L's operating people have given the green light for installation of the most advanced operating tool—a transistorized Desired Generation Computer.

A True Computer

Not only will the new computer mastermind automatic control of 19 units in all eight major plants, but it also can be used to solve complex load problems as an independent unit when disconnected from the control system. During the time the computer is used for other problems the control continues under the direction of the present equipment. When performing its control function, the computer will coordinate incremental transmission and generating costs using incremental heat rate, fuel cost and performance factor data. It will also be used to determine economic dispatch of 24 units—97 per cent of system capability. As a result, FP&L's already advanced Area Control will be boosted to a technological level exceeded by no other utility in the world.

Noteworthy Prediction

A 1948 board study of the FP&L system formed the basis of an AIEE paper* co-authored by FP&L's Manager of Power Supply, H. W. Page. This paper helped pave the way for development of dispatch computers

**AIEE Transactions T9242 "Coordination of Fuel Cost and Transmission Loss by Use of the Network Analyzer to Determine Plant Loading Schedules" by E. E. George, H. W. Page and J. B. Ward.*

Continued on page 274

JOHN SALZER **decentralizes computing-control**

A research associate at MIT in 1948 had an intriguing idea: why not combine his interest in digital computers with his interest in control systems to create a common technique for their analysis and design? His professors agreed that the concept was an interesting one, so John Salzer built his doctor's thesis around the representation of a digital computer as a network element in the control system.

When the thesis was published in 1951, the concept was still new, but his research had made Salzer a strong advocate of computing-control. At Hughes Aircraft Co., later that year, work on an airborne general-purpose digital computer changed his slant without diminishing his confidence in computing-control. As he puts it today, "The idea of controlling all facets of airplane flight and mission by a single, central digital computer sounded fine. However, it soon became apparent that a better way to solve the problem was by decentralizing the computing tasks."

This is the approach Salzer envisions for applying computing-control now. He sees "echelons" of computers. "Just as there have always been echelons of control loops, there will be echelons of control computers, both digital and analog. You can spot the trend even in production control, where computing-control is developing rapidly. Individual digital equipment is used to control a machine tool, but another computer—either automatic or human—decides which machine tool will do the job and when. We know the production process well enough not to suggest that a central computer should make supervisory decisions and control all the individual machine tools in the plant. It could be done but it would be very inefficient."

In his present position as director of systems at Magnavox Research Labs (which he joined in 1954), Salzer supervises work in such advanced computing-control projects as guidance and range safety systems for missile applications and the adaption of digital techniques to communication links. Although a potent advocate of computing-control, he warns against indiscriminate use of digital computers in control systems. "There must be real justification for inserting a digital computer in a control system," he philosophizes, "and unless the user thoroughly understands what the computer can and cannot do, he's likely to have a rude awakening."

For the future, computer specialist Salzer sees a movement away from large, general-purpose devices and toward specialized computers performing individualized tasks, each designed for its own specific job. He predicts, "These individual computing elements may be digital or analog, and they will have to fit into a carefully thought-out pattern for overall application."

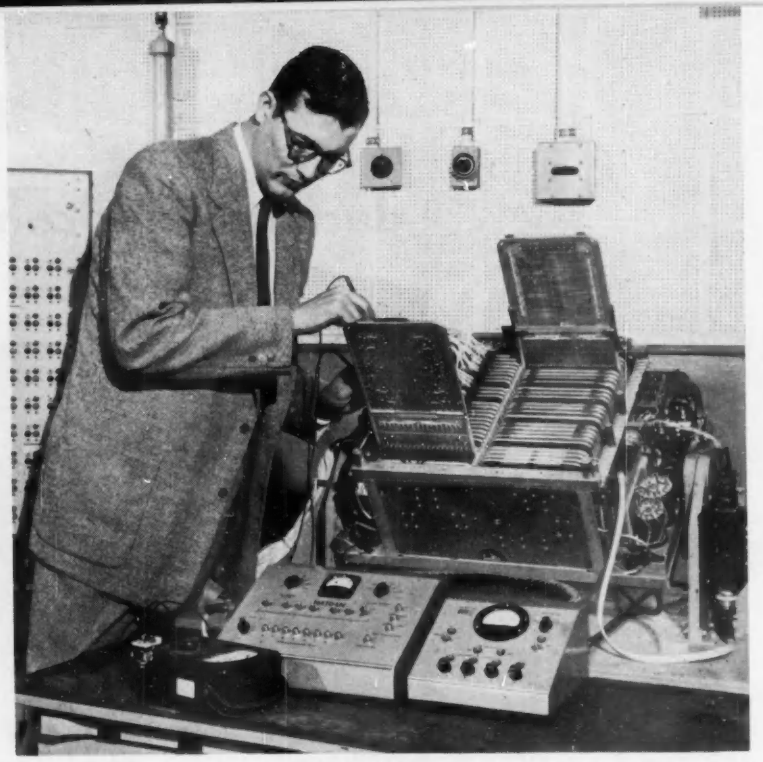
John Salzer himself has followed a tortuous path to his present interest in computing control. He was born in Austria and moved to Hungary just a week later. After high school he earned a living teaching languages and working as a furniture upholsterer. In 1940, he immigrated to the U.S., just in time to be inducted into the U.S. Army.

Discharged as a civilian in 1945, Salzer determined to get a formal technical education. He enrolled at Case Institute in Cleveland, and aided by his army training, he was able to earn a BSEE degree by the summer of 1947; by June 1948 he had received a MSEE.

Salzer's first encounter with computing-control happened that summer, when he was working at General Electric's Schenectady Engineering Laboratories. The problem: to apply an analog computer to control a lathe. His prior decision to enter MIT for doctoral studies in the fall prevented Salzer from going farther with this project than to work up a keen interest in the subject. Project Whirlwind at MIT gave him a full-blown introduction to digital computing and provided the opportunity to explore the potentialities of computing-control.

Today John Salzer is a far cry from the lonely immigrant who landed in New York 17 years ago: he just finished a year's tenure as chairman of the Los Angeles Professional Group on Automatic Control of the IRE and he still teaches night classes at UCLA. But two items in his home remind him of those early days: one is a U-shaped desk that furniture-maker Salzer built to satisfy a long-time yearning for "a desk with enough working space" and the second is a sofa that upholsterer Salzer fabricated as a hobby far afield from computing-control.

Digital computing-control stacks up as the most significant development in airborne control since the invention of the autopilot. Both the incremental computer and the general purpose computer are slated to play a big role in tomorrow's aircraft and missiles.



L. L. Kilpatrick of Autonetics Div. checks out "brain" of missile inertial guidance system, a transistorized DDA.

Digital Computers Earn Their Wings

At the Air Force Missile Test Center in Florida one day last spring, an X-10 test missile zoomed skyward, leveled off at its designated altitude and headed southeast towards an island target. In AFMTC's central control room, engineers watching the flight on radar plotters were wreathed in smiles as they saw the missile score a bullseye hit on the target.

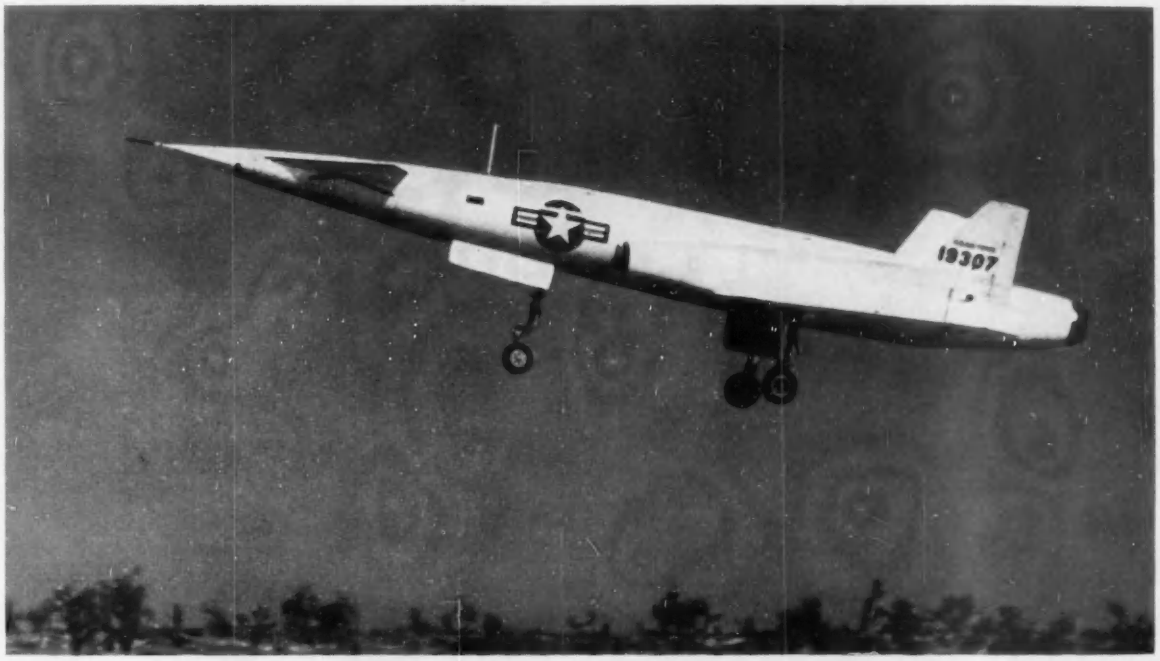
For Air Force control specialists the test had special meaning: it marked the 13th successful flight of this missile control system, proof that digital computing-control worked in the toughest application tried to date.

The fabulous DDA—Star performer in this test, and the previous 12 successful ones, was a digital differential analyzer (DDA), a miniaturized special purpose computer developed with airborne control systems in mind. The computer is connected into the control loop as an integral part of the missile control system. During a flight, the airborne DDA receives inputs from transducers that measure altitude and devices that measure position; it repeatedly solves navigation problems sending outputs to actuators that move rudder and elevator mechanisms to fly the missile to a target programmed into the DDA at the start of the test.

But the DDA represents only one-half the current effort in computing-control for supersonic aircraft and missiles. The general purpose computer is also coming into its own as an airborne controller. At the Air Force's Air Research & Development Command Headquarters, control engineers predict a bright future for digital computers in both aircraft and missiles (see Industry's Pulse, p. 109).

The boxscore—Military classification precludes any listing of the aircraft and missiles that are using digital computing-control (or will use it) but here's an indication of the activity in the control field:

- Hughes Aircraft Corp. has designed a computing control system for an Air Force Fighter plane using a GP computer; the company is now designing additional systems, one for a bomber and one for a missile.
- Autonetics Div. of North American Aviation has a transistorized DDA in production.
- Librascope Inc. is spearheading Navy development of airborne digital computers in control systems with miniaturized vacuum tube incremental computers. One Librascope design is now in production for a Navy attack plane; both GP and incremental transistorized designs are under study.
- Philco Corp. has built three transistorized GP computers (see box) for use in the control system of a U.S. Navy attack plane.
- Minneapolis-Honeywell's Aero Div. is studying aircraft systems using the Philco computer.
- IBM is developing both incremental and GP computers for airborne control systems.
- Lockheed Aircraft Corp. has an extensive R&D project underway in digital computing-control.
- Litton Industries has developed an incremental computer which Navy researchers are studying for possible airborne applications.
- Ramo-Wooldridge has built a small airborne computer which is be-



With flight instructions programmed into the memory of its airborne DDA, this X-10 test missile takes off at Patrick Air Force Base to prove accuracy of digital computing-control.

ing studied by Westinghouse's Air Arm Div.

• Bell Telephone Labs. has developed Leprechaun (CtE, Aug. '55, p. 34) to conduct research on digital computers for real-time control applications.

• At Wright Air Development Center, the Air Force has equipped a flying laboratory with digital computing-control.

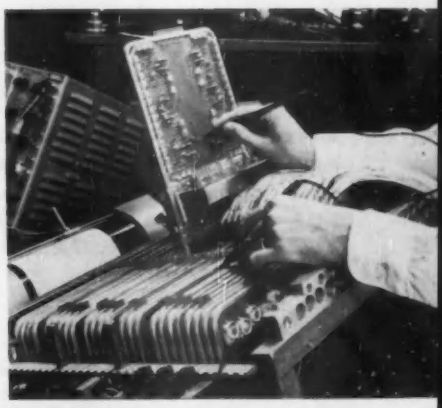
The first production aircraft to use digital computing-control, Control Engineering learned, will be the Navy's Douglas A3D attack plane with a Librascope incremental computer. Next application will probably be a modified version of the Air Force's F-102, which will be equipped with a Hughes general purpose digital computing-control system.

How it started—From conception to production has taken less than 10 years. Nine years ago, the Air Force first started thinking about airborne digital computers. At the time, analog computers were already established as part of the control system of the fast post-war jet planes. But the USAF was not completely satisfied with analog devices particularly when they were compared to the digital devices just starting to appear.

First, the analog devices tended to lose accuracy. Planners didn't feel that the accuracy obtainable with these computers would be satisfactory in the supersonic aircraft that were just starting to be designed. Analog computers were frequently hard to build; frequently required precision manufacture and complicated testing. And finally, an analog computer could be applied to do one function only; if you had more problems to solve you needed additional computers. A digital computer, on the other hand, was flexible and could perform a number of functions on a time-shared basis.

The airborne problem—In 1948 a digital computer meant a room-sized data processor with thousands of vacuum tubes. The first problem was to prove that a digital computer could be built small enough to fit into an airplane, let alone fit into the control system of the craft.

The handful of engineers studying the design problem pictured the computer solving a number of navigation and control problems over and over again as a flight progressed. They finally decided that an airborne computer didn't require a large capacity memory because the number of parameters and number of digits to be stored was low. And since the computer wouldn't solve a problem just once, (it would solve the same problem repeatedly) it was possible to cut down the amount of checking circuitry and equipment required. Engineers hypothesized that if the computers "dropped a digit" one time, it would correct the error the next time.



Innards of airborne DDA are designed to withstand mechanical shocks.

Working on this basis, Northrop came up with the digital differential analyzer concept in 1950. The first unit was a 22 integrator computer that occupied six cu ft in volume, a size that appeared to have sufficient capacity to solve navigational problems and was still small enough to get off the ground.

Progress with the DDA—Northrop's DDA solved problems by numerical

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REGULATION: In the range 0-30 volts, the output voltage variation is less than 0.02 volts for load variation from 0 to maximum current, and less than 0.02 volts for line fluctuation from 105-125 volts.
RIPPLE VOLTAGE: Less than 3 millivolts RMS.
FUSE PROTECTION: Input and output fuses on front panel.

OUTPUT #2

OUTPUT VOLTAGE DC: 0-30 volts continuously variable.
OUTPUT CURRENT DC: 0-1.5 amperes continuous duty.
REGULATION: In the range 0-30 volts, the output voltage variation is less than 0.02 volts for load variation from 0 to maximum current, and less than 0.02 volts for line fluctuation from 105-125 volts.
RIPPLE VOLTAGE: Less than 3 millivolts RMS.
FUSE PROTECTION: Input and output fuses on front panel.

RECOVERY TIME: Less than 50 microseconds. The excursion in the output voltage during the recovery period is less than .05 volts for line fluctuations from 105 to 125 volts or load variations from 0 to maximum current.

STABILITY: The output voltage variation is lesss than .05 volts for a period of 8 hours.

OUTPUT IMPEDANCE: Less than 0.1 ohms from 1KC to 100KC. Less than 0.01 ohms from DC to 1KC.

POWER REQUIREMENTS: 105-125 volts, 50-400 cycles.

OUTPUT TERMINATIONS: DC terminals are clearly marked on the front panel. All terminals are isolated from the chassis. Either positive or negative terminal of each DC output may be grounded. A terminal is provided for connecting to the chassis. The DC terminals are also brought out at the rear of the unit.

PHYSICAL SPECIFICATIONS: Height 7", width 19", depth 11", color gray hammertone. This unit is designed for relay rack mounting or bench use. Carrying handles are provided.

METERS: Voltmeters: Two 0-30 volts, 2½"
Milliameters: Two 0-1.5 amperes, 2½"

CONTROLS: Power on-off switch; outputs 1 and 2 DC on-off switch: outputs 1 and 2 ten turn voltage controls.

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WINGED COMPUTERS

STORY STARTS ON PAGE 26

integration. Its inputs were increments rather than whole numbers. Tests showed that it was more adaptable to control systems work than a GP computer, as long as there were no discontinuities in the inputs because the DDA cannot change abruptly.

The next big step in DDA design was brought about by the introduction of transistors. The Autonetics Div. of NAA built the first transistorized DDA in 1955. The use of semi-conductor devices cut its size in half.

The differential analyzer that flew in the X-10 missile tests occupied only 3 cu. ft., weighed 145 pounds and consumed 100 watts, just one-twentieth of the power required by its vacuum tube predecessor. The computer handles 93 distinct integrations and generates (in an incremental manner) continuous solutions of trigonometric functions and differential equations.

Philco's H. A. Affel (left) and C. C. Pond with the TRANSAC C-1100.

General Purpose research—While engineers were making giant steps in the development of incremental computers, still others were tackling the general purpose devices, a tougher nut to crack. Although the DDA showed tremendous potential in navigational control applications, aircraft designers could see applications that were beyond the capabilities of the incremental equipment. Example: the general purpose computer is more versatile; it can be programmed to solve any problem while the DDA can handle slow changes only, computing in "jumps", so that it has been called a "a digitized analog system". In addition, if you want to solve many differ-

An Airborne GP Computer

Compared to a general purpose digital computer built for data processing, the airborne GP is pint-sized. Transistorized to save space, improve reliability and reduce power requirements, the airborne computer is designed for high mechanical strength; it can withstand extreme temperature ranges, operate at high speeds and rely on small memory storage.

Typical of the GP equipment that has been designed for airborne computing control is the Philco TRANSAC C-1100 computer. Incorporated into the control system, it serves as an intermittent transfer element, optimizing navigation, cruise (fuel management) and weapons fire control functions.

The computer consists of six main functional units: 1) Input/output sections, 2) Arithmetic section, 3) Control section, 4) Core memory, 5) Drum memory, 6) Power supply and control box.

Despite its small size—3-cu.ft. volume, weighing about 160 lbs—, the C-1100 still has two memories. One is a drum memory for program storage; the other is a core memory for "scratch pad" storage during and between computations.

From a design standpoint, it is an Asychronous, parallel (for high speed) stored program computer intended for real time control systems. Philco reports it can perform as many as 1,300 arithmetic operations during its program cycle of 33 milliseconds. Short routines can be repeated on the drum to shorten sampling interval and increase bandwidth of the control system. For example, one common navigation problem, involving a conversion from rectangular coordinates to spherical coordinates in three dimensions, takes 3.4 milliseconds; this operation can be repeated to give a sampling rate as high as 300 samples per second. Other operation speeds:

Addition	25 microseconds
Subtraction	25 microseconds
Multiplication	75 microseconds
Division	75 microseconds
Square Root	75 microseconds
Absolute Magnitude	25 microseconds
Signed Magnitude	25 microseconds

Flexibility is another important design criterion. The C-1100 can modify its own program or constants depending on the results of the program—a feature particularly important in military combat aircraft whose controls are subject to damage which would cause them to exhibit abnormal characteristics. It can handle sudden changes in input data resulting from a switch in operating mode such as going from gyro input to celestial fix in a navigation system. And the computer is suitable for multiplexing among different functions such as autopilot, navigation, fuel management and weapons control.

The computer has an operating precision of 19 binary digits (one part in 1,000,000). In operation, input data received by the input section is converted to parallel binary form and transferred on demand to the arithmetic section. Outputs, usually control signals, are read out by the arithmetic section to the output section where they are converted into appropriate actuating signals.

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WHAT'S NEW

WINGED COMPUTERS . . .

STORY STARTS ON PAGE 26

ent problems, the DDA requires a redundancy of equipment, needing additional integrators and memory units. A final advantage is that the GP computer can be set up to modify its program if the aircraft controls should be damaged by enemy action or malfunction.

Because the GP computer is capable of making decisions on tests built into it, the Air Force has evolved its central computing concept around it—one computer solving navigation, fire control, fuel control and "shortest way home" problems on a time-shared basis. It is to be the "brain of the automatic take-off to touchdown" manned airplane. The DDA is being reserved for control applications that require only the solving of differential equations (such as in inertial guidance systems in missiles).

History of the GP—For a while it looked as if the GP computer would never fly. It wasn't until 1954 that Hughes Aircraft built the Digitac, a computer small enough to be loaded on a plane. It wasn't connected into the control system: Digitac's function was to prove that it was possible to get a GP digital computer off the ground in an airplane.

Just as in DDA development, the next big stride involved transistors: the transitorization of Digitac. It's this transitorized version that will be incorporated into the new F-102, the Air Force's first production aircraft to use digital computing-control.

In 1955, the development of Direct Coupled Transistor Logic circuitry at Philco Corp, permitted an additional improvement in airborne general purpose computers by reducing the number of components required. Philco built the C-1100 using only 3,900 transistors, 2,300 resistors and 280 capacitors.

Commercial liner potential—At this stage of technology; digital computing-control is set for a big future in military aircraft and missile. But there's a difference of opinion when it comes to talking about applications in commercial jet airliners.

Airframe manufacturers will tell you that computing-control is too expensive today for commercial airline operators. Miniaturization techniques and design to withstand temperature extremes have made digital computers uneconomic for airline use. And finally, the announced jetliners

—Douglas' DC-8, Boeing's 707 and Convair's 880—don't travel fast enough to require computing-control. It may be required on the next generation of commercial transport that travel at speeds greater than 1,000 mph,—at least ten years off according to one estimate.

But at least one computer manufacturer, Philco Corp., argues for computing-control on the current crop of jetliners. Philco claims that digital cruise control on a jet liner would almost pay for itself in fuels savings on just one long nonstop trip such as between Los Angeles and New York. The cruise control would optimize fuel efficiency, says Philco, by putting the airliner in the best jetstream for a particular trip, making sure the plane gets into the jetstream and computing the time to leave the jetstream to start the approach to land.

The Air Force has some evidence to support Philco's thinking. At Wright Air Development Center, the Air Force has conducted a variety of tests with a digital cruise control and found extensive savings were made possible by its use.

Other Digital Devices—To those working on digital computing-control, one of the biggest headaches is the lack of digital input and output equipment. All digital computing control in use today has to rely on analog to digital converters and then digital to analog converters. One of the biggest areas of research now is to develop new input-output equipment.

There are other areas under study too. The Air Force is working on a digital autopilot. Just recently, Librascope announced it had developed a light-weight digital auto-navigator under WADC sponsorship.

And development of the so-called Incremental Computer (see article on page 166) promises to expand application of the DDA. The Incremental Computer—an extension of digital differential analyzer techniques—solves a single basic equation for each step of a program. This adds a degree of flexibility so that such equipment approaches a general purpose computer in versatility.

All this activity mirrors a new trend in airborne control systems. It has opened up a big new market for equipment suppliers interested in digital devices (estimated cost of a transistorized DDA: $50,000 to $75,000). And "putting wings" on digital computers represents a major technological advance.

The Air Force now feels that digital computing-control is out of the laboratory stage. As proof, starting in fiscal 1958, expenditures for control equipment will be divided about 50-50 between analog and digital equipment.

indicates set point and process variable at a glance!

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- Standard proportional band 1-100% . . . also available to 150%.
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- Manual reset readily accessible. Automatic reset optional.
- Compact—8⅝" square x 4" deep.
- Pneumatic feedback circuit with sensitivity of 1/10% and repeatability of ½%.
- Available in a variety of temperature ranges; pressure ranges from 0-30" H_2O to 0-10,000 psi, and in vacuum ranges of 0-30" Hg.

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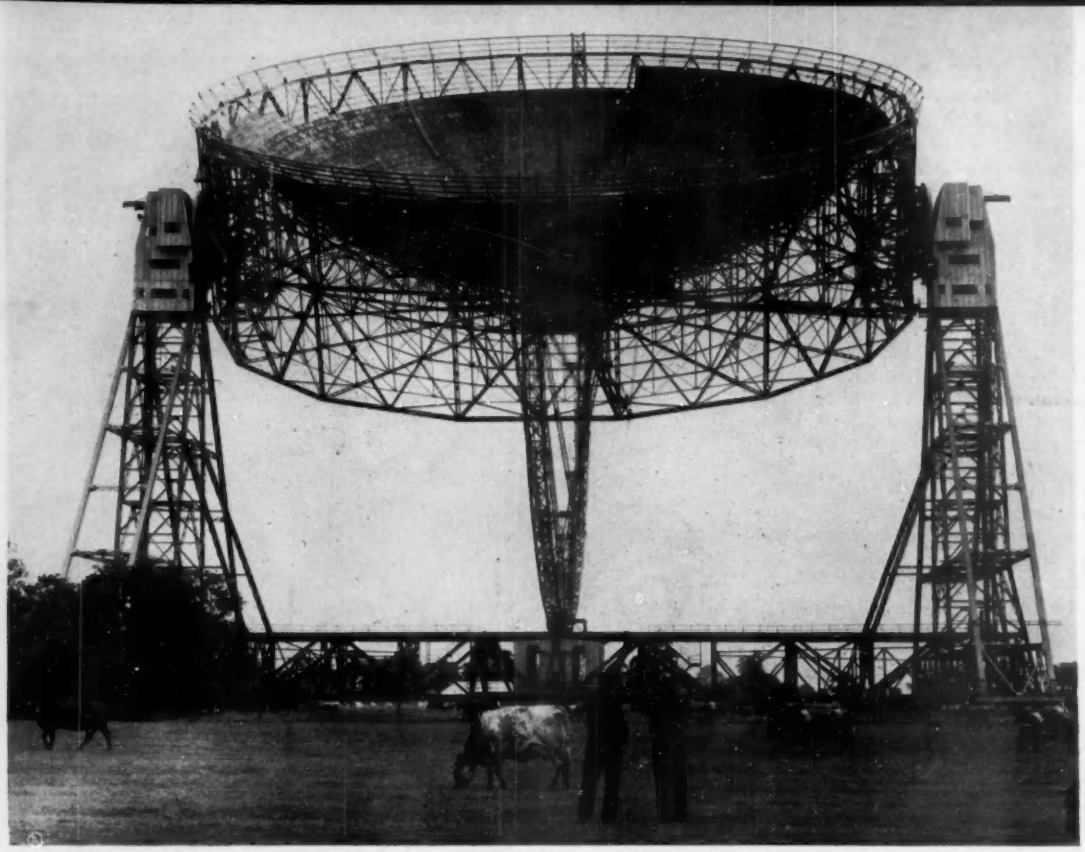
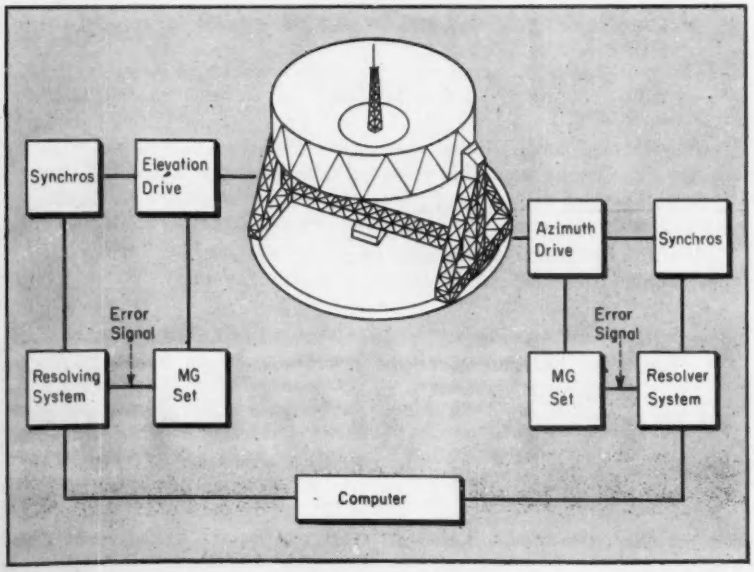


Giant radio-telescope consists of a 250 ft-diameter reflecting surface cradled between towers in a bowl of structural steelwork.

Largest Steerable Radio-Telescope

. . . positioned to 12 min of arc by computing-controlled servo system.



LONDON—

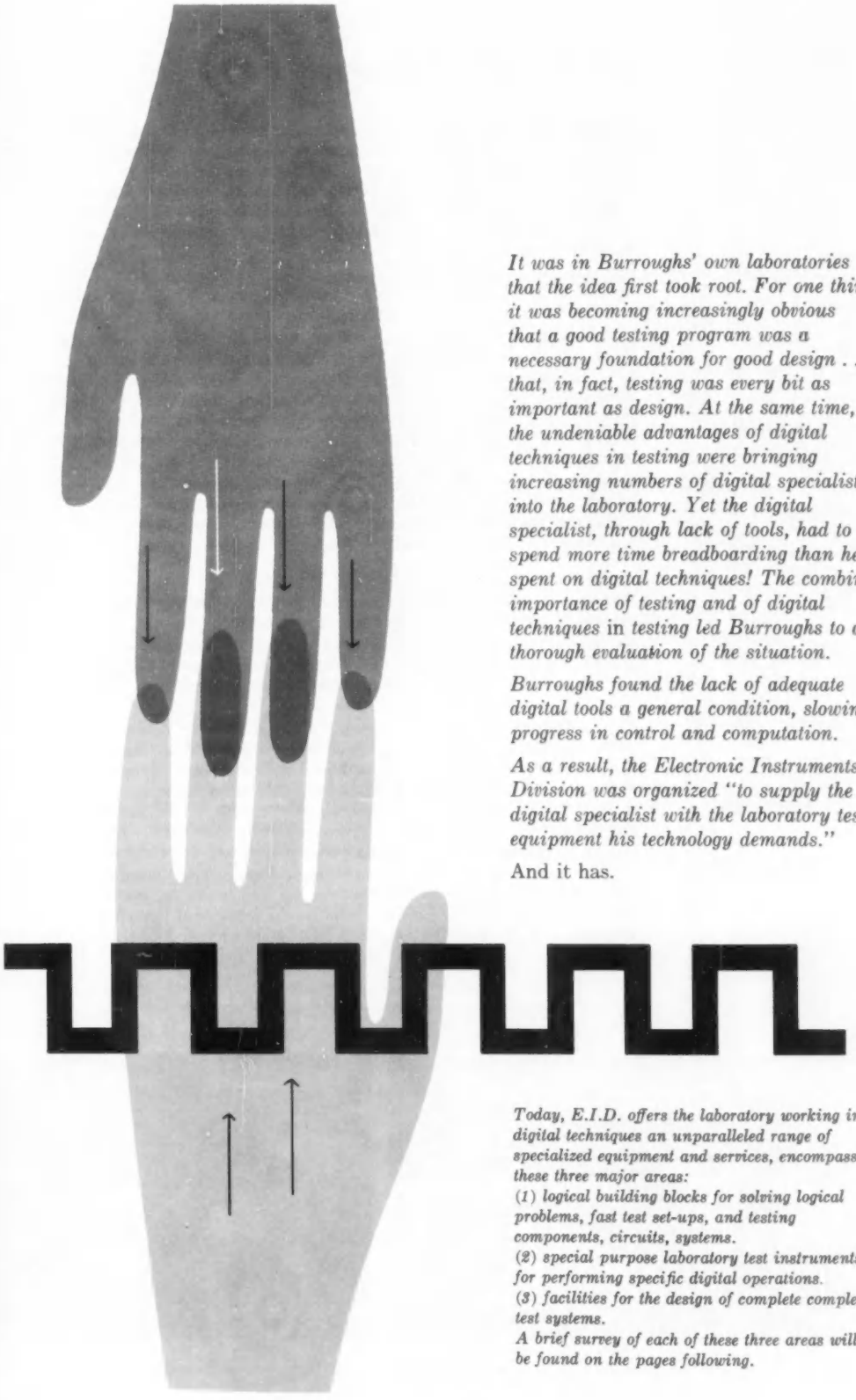
A new, $2.5-million steerable radio-telescope—the world's largest—will start operating this month in a meadow outside the country village of Jodrell Bank. To control and position the 2,000-ton structure, British engineers designed a unique computing-control servo system. Its heart: a Dunford & Elliot electromechanical analog computer that 1) solves 14 trigonometric equations from the inputs of sidereal time and astronomical coordinators, and then 2) sends signals to the main driving system.

• **Telescope operations**—Scientists who will use the giant instrument for radio-astronomy research at the University of Manchester decided the unit had to be able to perform three separate functions:

▶ Tracking—in which the telescope is locked on to the course of a radio source as it moves across the sky.

▶ Scanning—where the arc of the sky

(*turn to page 37*)



digital techniques in the laboratory

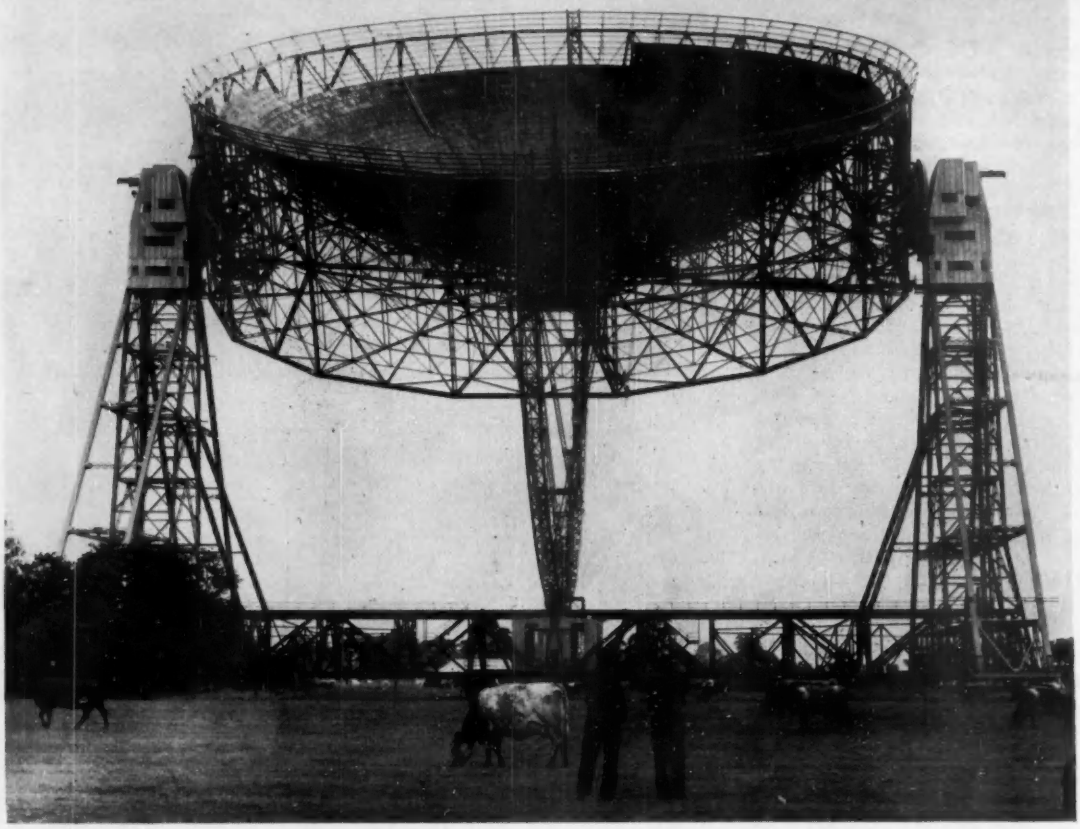
It was in Burroughs' own laboratories that the idea first took root. For one thing, it was becoming increasingly obvious that a good testing program was a necessary foundation for good design . . . that, in fact, testing was every bit as important as design. At the same time, the undeniable advantages of digital techniques in testing were bringing increasing numbers of digital specialists into the laboratory. Yet the digital specialist, through lack of tools, had to spend more time breadboarding than he spent on digital techniques! The combined importance of testing and of digital techniques in testing led Burroughs to a thorough evaluation of the situation.

Burroughs found the lack of adequate digital tools a general condition, slowing progress in control and computation.

As a result, the Electronic Instruments Division was organized "to supply the digital specialist with the laboratory test equipment his technology demands."

And it has.

Today, E.I.D. offers the laboratory working in digital techniques an unparalleled range of specialized equipment and services, encompassing these three major areas:
(1) logical building blocks for solving logical problems, fast test set-ups, and testing components, circuits, systems.
(2) special purpose laboratory test instruments for performing specific digital operations.
(3) facilities for the design of complete complex test systems.
A brief survey of each of these three areas will be found on the pages following.



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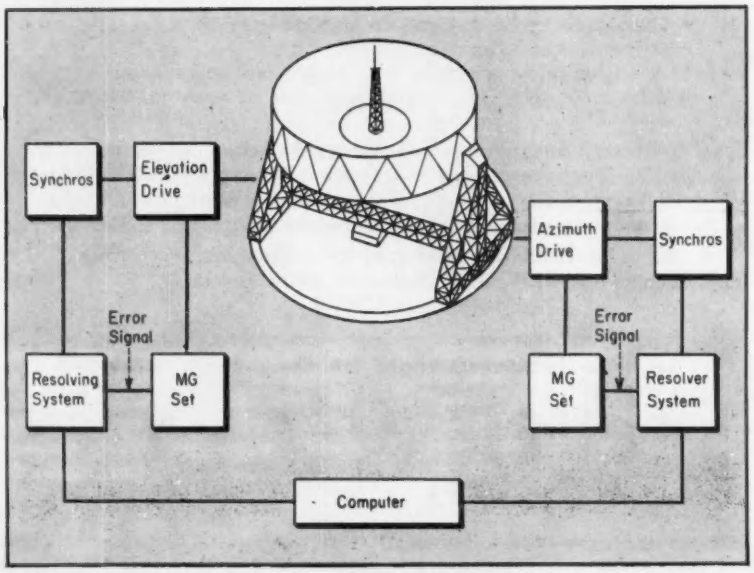

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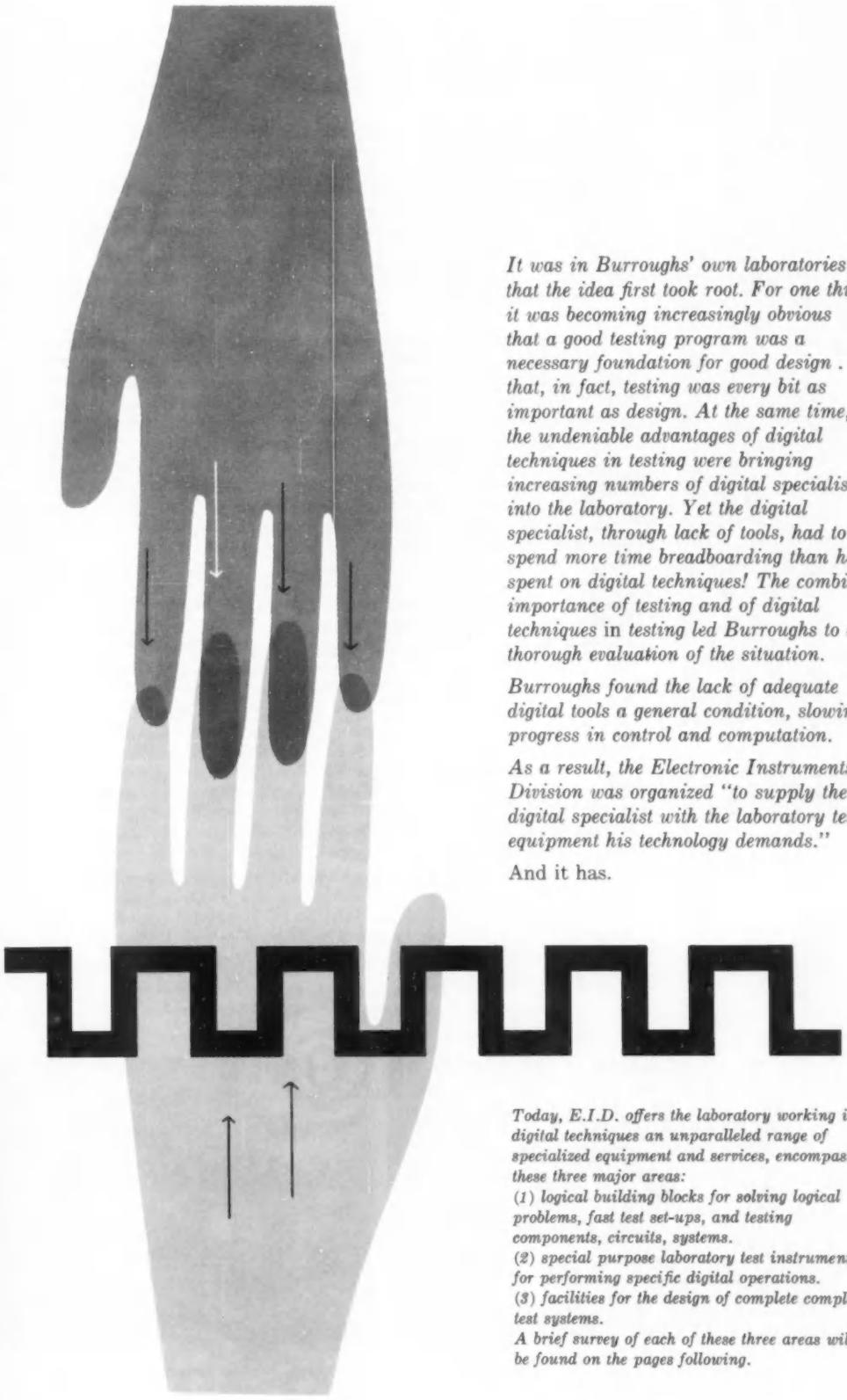
(turn to page 37)



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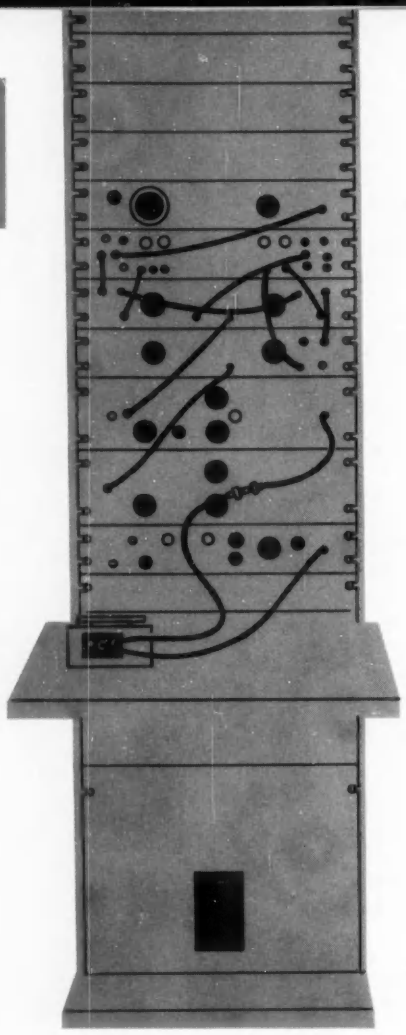
1



general purpose test equipment

The most apparent need of the digital designer, and the first satisfied by Burroughs, was that of general purpose test equipment of the building block variety. Without them, he was tied to the breadboard . . . building pulse equipment and logic circuits from basic components . . . spending more time proving the solution than solving the problem. But with the Unitized Pulse Control Equipment introduced by Burroughs, his creative efficiency rocketed skyward.

Made up of individually packaged logical concepts . . . translations into hardware of the blocks of the everpresent block diagram . . . the units quickly earned the title "tools for engineers".

With the solution in block diagram form, the designer merely set up the Burroughs pulse control "blocks" in a standard rack . . . made simple interconnections reflecting the flow lines of the diagram, moving directly from solution to proof. Original ideas or hunches were quickly and easily brought to working reality. Breadboard hardware was completely eliminated. And, on the spot modifications involved little more work than erasing one flow line, substituting another.

As a unique service, Burroughs offers, with the equipment, the problem solving facilities of its own logical design group. Typical problems solved by this group and proved on Burroughs pulse control equipment are illustrated below.

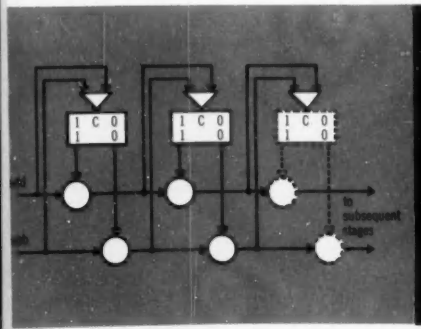
* * *

Among the early applications for pulse control equipment were several component evaluation patterns.

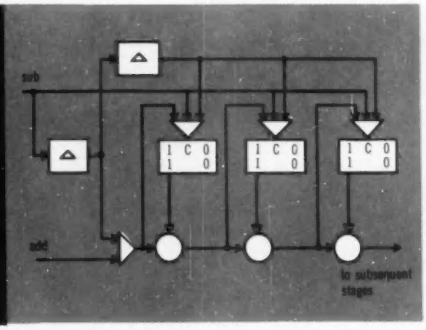
The ideal way to test a digital component, is to observe its behavior under actual operating conditions. Burroughs Pulse Control Equipment proved to be an efficient and economical means of simulating the conditions which can arise in a digital system.

One of the most unique applications of this was Burroughs development of the BCT-301 . . . a completely flexible test system which simulates certain core system conditions. Built up of standard pulse control units, it includes a specially engineered testing jig, calibrating device, and current drivers. The BCT-301 proved so successful in Burroughs own core program that it was marketed to industry. Today, it can be found at the heart of testing programs of numerous core manufacturers and core users.

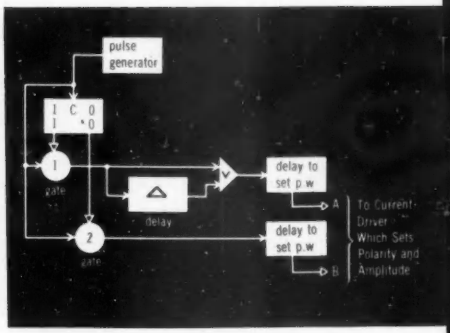
Whether you're solving logical problems or testing digital components, Burroughs experience is at your service. You can obtain technical literature and papers by checking titles on the reply card opposite and dropping it in the mail. Or, send us a description of your testing problem. We'll gladly work out a Pulse Control solution at no cost to you.



2.5 megacycle bidirectional counter



A 500 kc bidirectional counter which saves equipment when the number of stages is large



Pulse control diagram for testing tape wound cores

2

special purpose instruments

Perhaps the most important reason for the growth in digital techniques in the laboratory has been the precision permitted by digital methods in comparison, measurement, and counting. Special purpose instruments make it far easier for the laboratory to benefit from these advantages. Of the complete line of such instruments available from the Electronic Instruments Division, four typical units are discussed here.

New instruments will be added to the line as soon as the need arises. We therefore welcome your inquiries, and would particularly appreciate a statement of your requirements.

precision delay generator 6010

Provides accurate, variable time interval pulses. Three modular subsections include a trigger generator permitting fast or slow triggering, which can also function as a self-contained pulse generator . . . a delay generator producing five stable outputs . . . and a power supply. Outputs include positive and negative delayed pulses, positive and negative gating pulses, and a linear negative going ramp function. Pulse interval ranging from 1 to 10,000 μsec is controlled by a calibrated delay dial and associated 5-position switch.

high frequency pulse generator 1050

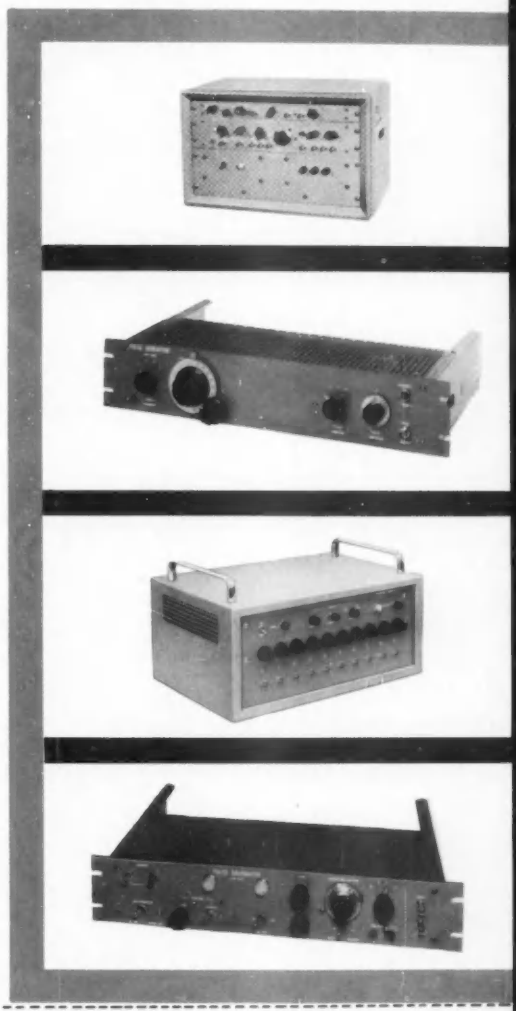
High frequency pulse source for switching circuits in the 10 megacycle range. Produces half-sine wave voltage pulses at frequencies continuously variable from 1.6 to 10.4 megacycles in four overlapping bands. Pulses are available in five different widths, and amplitude and polarity are knob controlled.

beamplexer

A unique laboratory tool for displaying up to ten separate inputs on a scope face simultaneously, the Beamplexer is actually an extremely fast electronic switch. Parallel input signals are taken off in sequence at adjustable speeds from push-button to 100 kc. Signals can be located on the scope as desired through individual positioning pedestal controls for each channel.

calibrator 1810

Has been especially designed to measure currents and voltages associated with the evaluation of magnetic cores under pulse conditions, but can be used where ever precise calibration of voltages and instruments is required. It provides a visual means for calibrating the driving pulse with an error of less than 0.1%, and will measure the output amplitude in millivolts.



Gentlemen:

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NAME_____, TITLE_____

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I am also interested in test systems design in the following areas:

_____

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building blocks

- Unitized Approach
- Core Tester BCT-301
- What Pulses Can Do For You
- 4 Dimensions in Digital Design
- Pulse Patterns For Testing Cores

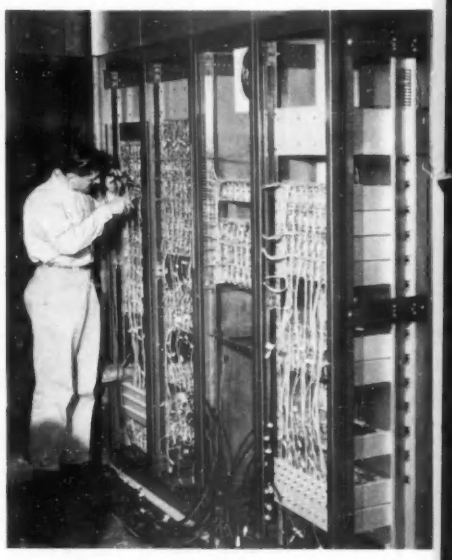
special purpose instruments

- Delay Generator 6010
- Beamplexer
- Pulse Calibrator 1810
- High Frequency Pulse Generator

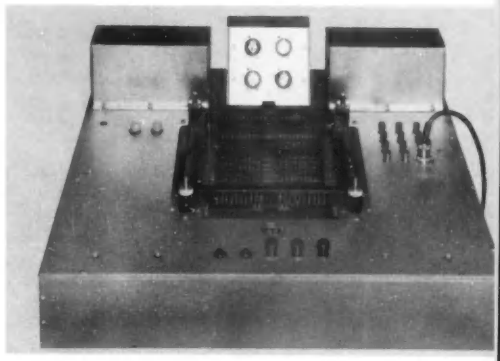
3

complete systems design

While Burroughs pulse control units are ideal laboratory tools for solving logical problems in computer design . . . testing individual components for pulse circuitry . . . performing specific digital operations . . . there are design and test requirements so complex as to require an entirely different approach. Designing and testing a complete core memory, for example . . . or building and testing complete digital computer subsections. Actually, both these jobs have been done by Electronic Instruments Division with Burroughs equipment. But chances are, they could not have been done successfully without the full-time efforts of Burroughs logical circuit and logical hardware designers . . . the men who developed the equipment. Should your needs be of this order of complexity, their experience and knowledge are available to you. Electronic Instruments Division can either serve you in a consulting capacity . . . or design, develop, and install the entire system from start to finish.



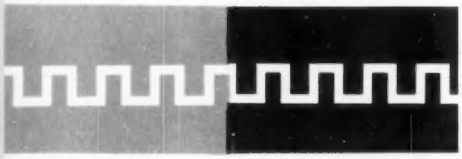
Installing Magnetic Memory For Large Computer



Memory Plane Tester

Burroughs Corporation Electronic Instruments Division

1209 VINE STREET PHILADELPHIA PENNSYLVANIA

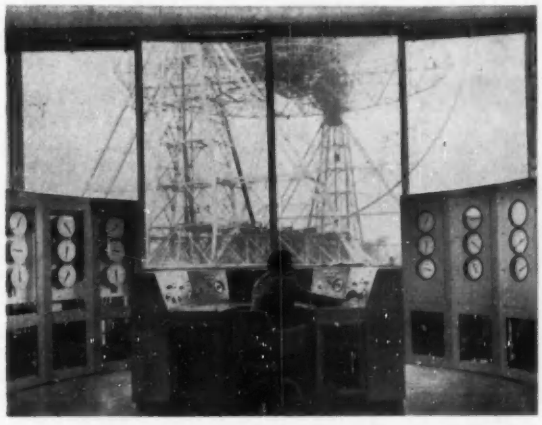


FOR FURTHER INFORMATION

Complete the reply card on the other side of this sheet . . . insert in an envelope, or attach to a postcard . . . and mail to Burroughs Corporation, Electronics Instruments Division, 1209 Vine Street, Philadelphia 7, Penna. Your request will be given prompt attention.

tools for engineers

Burroughs



Control room, 200 ft from telescope, contains analog computer and gives operator overall view of the big instrument.

to be scanned can be set in any of three types of coordinates (terrestial, galatic, or celestial) with the scanning master steps dependent on time or position.

► Traversing—rapid movement from one present position to another.

In addition, they wanted position accuracy within 12 min of arc.

Two British companies teamed up to supply the control system. Dunford & Elliot built the computing portion, while the Brush Electrical Engineering Co., Ltd., provided main drive controls and assembly.

Design of the computer was complicated by its fundamental requirements, particularly scanning. In this operation, the computer has to scan in any one of the three sets of coordinates used by astronomers; its rate of scan is variable; and the elevation rate is time- or positioned-control. As a final tough specification, D&E had to provide in the control room an indication of the telescope's actual position in terrestial, galatic, and celestial coordinates.

• **Computing-control at work**—Control signals from the computer (housed in the control room 200 yards from the telescope) operate the main drive assembly (see schematic). A fine course synchro resolver system with an accuracy of better than 1 min of arc supplies azimuth position through couplings on the center pivot of the aerial assembly. In the elevation position, pickoff is from another set of double synchros mounted on the trunnions in the towers. Both of these motions are transmitted to the synchros by chain drives with anti-backlash devices.

The error signal—produced by comparing the computer signal and the resolver signal—controls the excitor field of an mg set which drives four variable-speed 50-hp dc motors for each axis. Accuracies of the system have not been verified as yet. But designers figure that the computer solution will be within 4 min of arc and the driving system within 5 min of arc—easily achieving the specification of 12 min of arc.

Initial research to be conducted with the giant telescope: locate sources of radio emission 200 million light years back, emission in the one-to-two-meter band. Prof. A. C. B. Lovell is heading up the research.

G&L Ships First Five-Axis Machine

In June 1955, machine tool builder Gidding & Lewis held the first public demonstration of its Numericord system, a numerical control for machine tools (CtE, Aug. '55, p. 12). In July 1957, G&L was ready to announce two more Numericord milestones:

► Shipment of the first variable-axis, airframe profile milling machine operated solely by magnetic-tape commands to Lockheed Aircraft Corp. in Burbank, Calif. for production of parts for the high-speed F-104.

► Final cutting tests and Defense Dept. approval for a production model spar and skin milling machine, also equipped with numerical control. G&L will ship this machine soon to The Martin Co., Denver, Col.

• **Initial deliveries**—Both machines represent initial deliveries on quantity orders for numerically controlled airframe milling machines placed at G&L by the Air Force's Air Materiel Command. At last report, AMC had ordered 16 G & L-Concord Control tape preparation desks (which convert blueprint information into numerical

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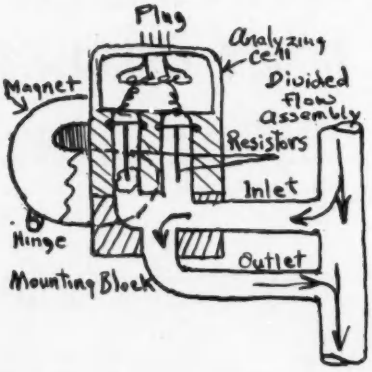
RAMBLINGS ON INSTRUMENTATION

How to Build O_2 Analyzers for Fun and Profit—Step 2

This is the second in a spasmodic series of do-it-yourself instructions for those who are either too proud or too poor to buy their oxygen analyzers from Hays, but still want nothing but the real, finicky Hays construction. Our first lesson, termed by some loyal readers "the best tranquilizer they've come across," told how anyone with a little skill and working capital can amaze their chums with genuine Hays-type precision sensing elements.

Our next step is to mount these two elements within an analyzing cell (see artist's impression below). Cram in two more precision resistors to complete a standard Wheatstone Bridge (named for its inventor, Sir Wheatstone Bridge, Cambridge '01). Bring the leads out the top at some convenient point. Don't forget to seal the upper end of the two chambers so that gas cannot flow through them. This prevents dust or moisture from settling out, a problem with other designs.



Put the cell on a mounting block, being careful to provide an inlet and outlet for the gas. Diffusion will bring about an exchange of gas within the cell block itself.

Now get hold of a 3300 gauss plus Alnico 5 magnet of at least 20 pounds weight (watch your paper for sales). Stabilize this at about 2500 gauss and mount it on a hinge so it can be swung away from the analyzing cell for zero checking. Now you're ready to fire up. Better wait for our next lesson for this (or write for our bulletin 56-829-56 to bone up). Should you decide to go it alone, lots of luck.

Our ad manager, who yearns for a good old hard-sell product ad now and then, insists that, while we're rambling about O_2 analyzers, we include a reference to our Mark II analyzer available very soon. It incorporates the divided flow assembly shown here. Only a small portion of the total gas actually passes through the analyzer. This maintains high response to sample changes, yet holds down possible damage caused by particles of foreign matter bounding through the system.

For do-it-yourself fans, we have a conversion kit available to bring your instrument up to date. It includes parts, step-by-step instructions, drawings and three Band-Aids. We'll be happy to send you details.

How to Get Off a Tenterhook

Our bated-breath bulletins concerning the new Hays Universal Recorder have fanned a flame of curiosity among recorder enthusiasts everywhere. While we still can't sell you one, darn it, we'd be very happy to show you our new baby in the flesh at our exhibit at the ISA Show in Cleveland. We're in booth 1013. Drop in.

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WHAT'S NEW

data on punched tape) and six G & L-Concord Control director systems (which convert the punched tape into the magnetic tape that actually controls the mill).

To-date, only two of the directors have been located. The original is at G&L in Fond du Lac, Wis.; the second will be placed at Boeing Aircraft's Wichita, Kan., plant. Eventually, AMC contractors with Numericord controlled tools will send their paper tapes to the nearest director for conversion to magnetic tape.

To speed up putting Lockheed's machine into actual production, finished operating tapes for a number of aircraft parts have been prepared on the Fond du Lac director.

• **Introducing Variax**—The Lockheed machine also represents the first production model of a new family of G&L variable-axis-control, profile airframe milling machines. The company has named the new line Variax.

The new machines combine 1) horizontal movement of the column on its runway; 2) vertical movement of the saddle on its column ways for 360-deg path control in the plane of the angle plate where the work is mounted; 3) depth motion through movement of the head along the spindle axis; 4) head swiveling in the saddle plane on segmental ways to achieve a transverse tilt function; and 5) column swiveling.

• **Missile producer**—Martin's machine is a standard-design G&L spar and skin milling machine that has been equipped with numerical control. It will be used for production of the "Titan" missile.

Numerical Control Group Formed in Japan

Japanese engineers interested in the application of numerical control to machine tools have formed the Society of Numerically Controlled Machine Tools (SNCM) in Tokyo, Prime movers behind the organization were: Dr. Y. Ukita and S. Sajiki of the Government Mechanical Laboratory and Prof. Y. Oshima of Tokyo University.

In a summer meeting, the group elected Dr. Masao Sugimoto, director of the Government Mechanical Laboratory, head of the society, and discussed the U.S. Aircraft Industries Association report on Numerical Control (CtE, Aug. '57, p. 29).

NOW! Cash Standard-Sparton brings you the World's First

Packaged Remote Control System

regulates final control elements governing

- **PRESSURE**
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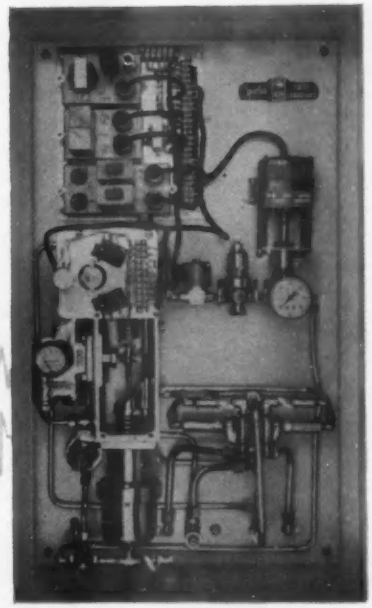
- **SPEED**

and other process variables



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For remote location at distances of a few feet to many miles. Operates on telephone, telegraph, private lines or microwave.

Now—for the first time in a single package system—it is possible to control, from a distance of many miles if necessary, the positioning of cone, butterfly, plug and ball valves; sliding stem valves; throttles, rheostats and other variable speed mechanisms; and similar final control elements.

The unique Series 300 Packaged Control System, developed by A. W. Cash Company and Sparton Corporation, reduces operating costs substantially through regulation of final control elements by one operator from one central point. As a result, the equipment pays for itself rapidly. It is recommended particularly for such applications as pipe lines, pumping stations, oil wells, storage tanks, power stations, municipal water distribution, petroleum and chemical processing and atomic energy processing.

For complete information on the remarkable new Cash Standard-Sparton Series 300 Packaged Control System, see the Cash Standard control specialist in your area, or write to Dept. F.

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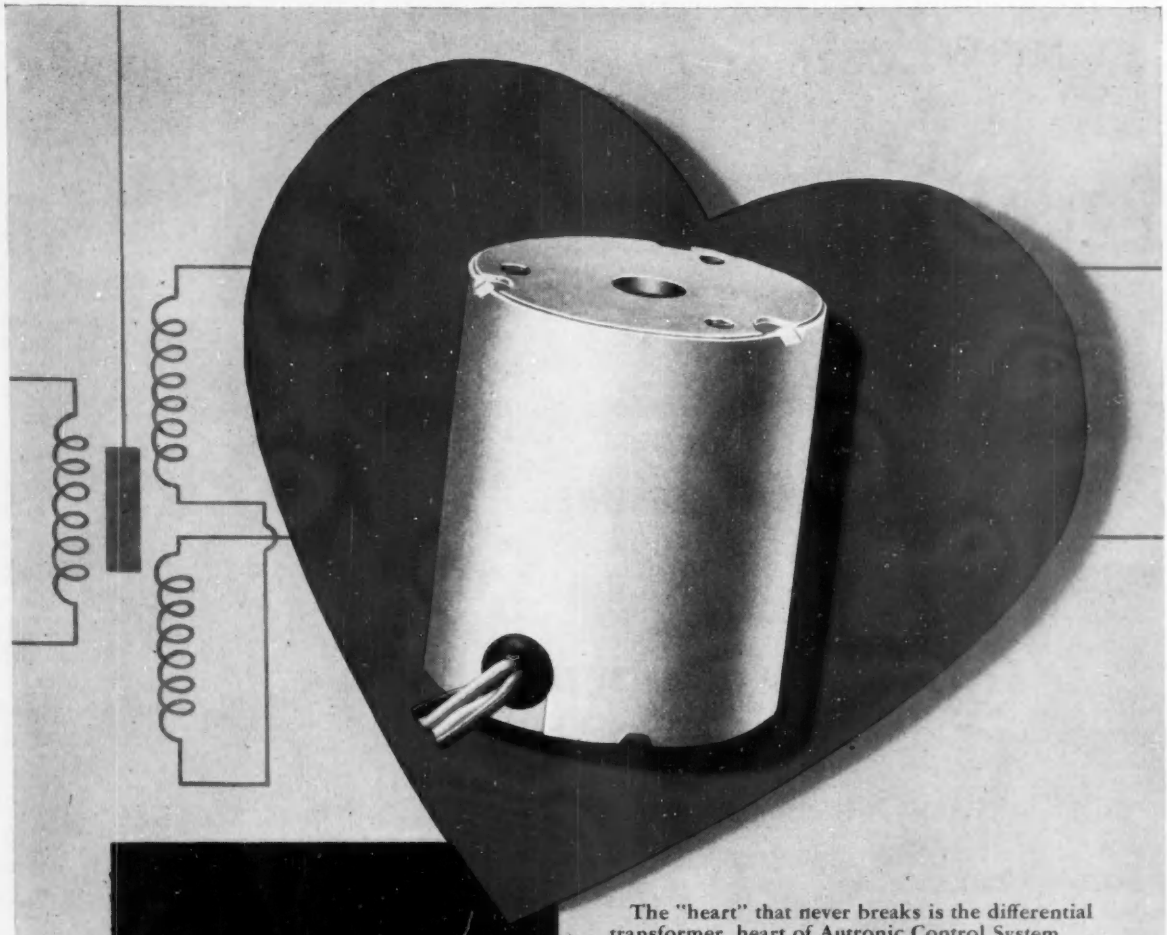
Pressure, Hydraulic, Temperature, Process and Combustion Controls



here's the heart that never fails in

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The "heart" that never breaks is the differential transformer, heart of Autronic Control System transmitters.

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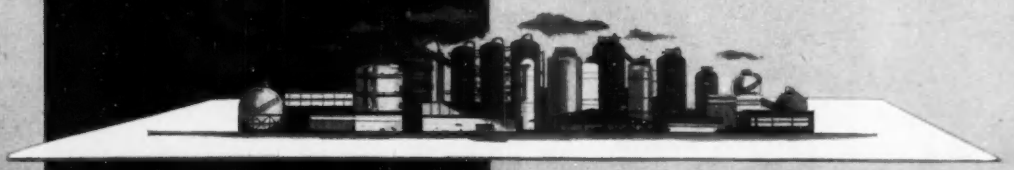

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British Study Computing-Control

***Control Engineering's* European editor reports lack of analysis instrumentation and capital defer acceptance of computing-control**

LONDON—
Britain's look at computing control is essentially a long term one with a lot of brainwork involved but as yet little hardware installed.

Two schools of thought exist among British control engineers on the method of incorporating the computer within the loop. One advocates a conventional approach with the computer providing the controller settings to individual loops. In the other, the computer transmits control signals direct to the regulating units. A roundup of opinion in the petroleum and chemical industries showed a surprising preference for the sophisticated approach.

Directly associated with interest in computing control is the increased emphasis on quality measuring instruments for input and output analysis. This is a new trend, quite opposite to earlier thinking in which engineers sought more accurate transducers for the basic elements such as temperature, pressure and flow. These were used to infer quality analysis rather than to employ a direct analysis.

As a result the plant on the in-out system could operate over a range of conditions with the main control exercised by the in-out quality analysis instrumentation, instead of operating at a fixed point in its characteristic.

Advantages claimed for this technique: 1) controllers can revert to single term; 2) high accuracy flow, temperature and pressure transducers are not required, provided that the quality of instrumentation is adequate; 3) the use of fluid couplings in lieu of control valves; 4) normal flow, temperature, pressure readings can be used as redundant information for computer checks; 5) the system is less susceptible to false signals.

Although advanced thinking is going on in both schools, lack of knowledge about process dynamics, the question of computer reliability and the lack of quality analysis instrumentation is seriously holding up actual installations. Some engineers feel that the British are as much as three years behind U. S. in computing-control applications, a situation aggravated by less ready capital in the United Kingdom. In addition, British industries require a project to be shown economically profitable before installation, another factor retarding acceptance.

—Derek Barlow

New Digital Computer for Process Control

Although many computer manufacturers feel that their data processing equipment can double in computing-control applications, a number of experts close to the field believe that economical computing-control in the process industries calls for a computer specifically designed for that purpose. In July, electronic manufacturer Ramo-Wooldridge Corp. joined the special design school of thought: R-W announced a general-purpose digital computer, the R-W 300, to serve as the central unit of a process control system.

Behind the announcement was a year of special studies, unique in computer design. R-W researchers first studied industries they thought were potential users of computing-control: petroleum processing and oil refining, chemical manufacturing, cement, paper manufacturing and metal processing. They determined how many and what kind of inputs a process controller would need; the number and type of outputs; the speed of operation, and additional functions such equipment should perform.

Next step was to simulate the logical structure of the proposed computer design on a Univac 1103. The simulated computer was made to perform a simple sequence of instructions to check logical design.

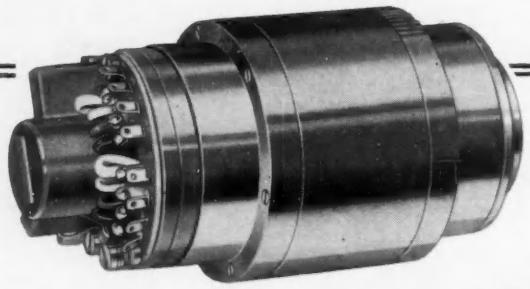
• **Payoff in three years**—The studies turned up some interesting facts. According to R-W the payoff for a computing-control system takes place within from one to three years, stemming from 1) increased plant throughput, 2) improved product quality and 3) reduced operating costs. No process required more than 300 inputs or 150 outputs. And, in typical applications, the main part of the control problem could be solved by the computer in 1-3 min.

Other functions besides computing can be performed by the R-W 300. These include: data logging, process and instrument checking, instrument calibration, economic and statistical analysis.

• **Design features**—From a design standpoint, the R-W 300 is a general-purpose, magnetic drum storage, stored program, serial machine. It uses binary numbers internally, although decimal outputs to appropriate units can be supplied through use of a conversion routine. The computer has a word length of 17 bits plus sign.

The machine uses a "one-plus-one-address" instruction, which allows for an unconditional transfer with every command. That means effective computer speed is increased and computer programming made easier. The machine also has a provision for less than full length multiplication and division, a feature which a programmer can use to reduce computing time.

R-W hasn't sold any of its process control computers as yet, although the company says there are a number of industries studying it. The computer maker believes that its first applications will probably be as trimmers on conventional control systems rather than as main process controllers.



2″ Magslip Feedback Resolver

E-64-C/1 2″ RESOLVER TRANSMITTER

The widely used Muirhead 3″ Resolver Transmitter No. 2 (feedback resolver) is now available in a 2″ Magslip frame. Designed for inputs 0-25 volts 50 c/s, this new instrument gives equal performance to the 3″ Resolver.

Accuracy: Maximum voltage error ±0.1%
Maximum angular error ±0.05 degree

The Resolver is used primarily for electrical computation for obtaining outputs proportional to the product of the sine or cosine of the rotor displacement angle and the input voltage. The feedback feature enables the instrument to maintain its high degree of accuracy for varying voltage inputs.

Applications of the Feedback Resolver include:—
Interchanging Polar and Cartesian Co-ordinates.
Rotation of Rectangular Axes.
Solution of Triangles.

A data sheet for the 2″ Resolver Transmitter E-64-C/1 giving all electrical and mechanical information is available on request.

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WHAT'S NEW

Symposium Features Computers in Control

Computers in Control will be the theme of a symposium to be held in Atlantic City, N. J. at the Chalfonte-Haddon Hall Hotel in Atlantic City, October 16-18, 1957. The conclave, sponsored by the AIEE Feedback Control Systems Committee with participation by the IRE Professional Group on Automatic Control and the ASME-IRD, will have an international flavor induced by the attendance of Tsypkin of Russia, Pelegrin of France, and Barker and Blackman of England.

Subject matter to be discussed: the use of digital and analog computers as elements of feedback control systems and the design of computing-controlled systems.

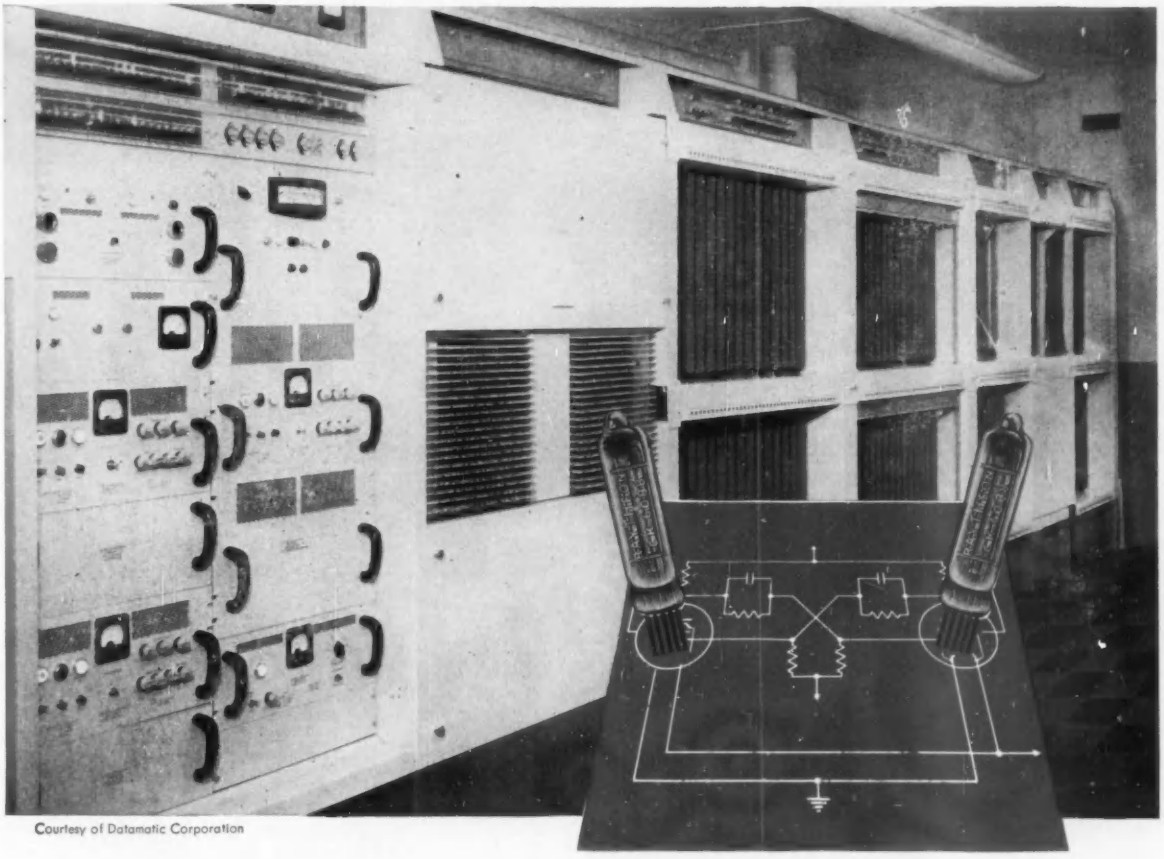
Report on Basic Research

National Science Foundation has completed a report on how money was spent for basic research in 1953, the most recent year for which such data is available. The analysis showed that funds for basic research totaled $435 million, 8 percent of the estimated total of $5.4 billion spent for research and development in the U.S. in 1953.

The study also showed that colleges and universities were the principal performers of basic research (defined as the pursuit of new scientific knowledge), accounting for $205 million (47 percent of the total); industry ranked second spending 39% of the total; Federal government ranked third with 11 percent, and other institutions accounted for the remainder.

Computing-Control On the Range

U.S. Navy has awarded a contract to Feedback Controls, Inc. for an Aircraft Vectoring Study at the Navy's Aircraft and Missile Test Range, Pt. Mugu, Calif. The new system is aimed at improving coordination between "attacker" and "target" during missile and aircraft tests. The approach: use computers, located in the ground-based control room, to bring the "attacker" into prescribed relationship with the "target," and provide fully automatic test results.



Courtesy of Datamatic Corporation

Cut flip-flop circuit power requirements 95% increase reliability and eliminate the heat rise problem

with RAYTHEON FILAMENTARY SUBMINIATURE TUBES

Here are the figures on CK6418 and CK6088 power input as compared with a popular heater-cathode tube such as CK5814

	plate supply	power per 1000 flip-flop circuits
CK6418	30 volts	29.5 watts (2000 tubes)
CK6088	45 volts	63.5 watts (2000 tubes)
CK5814	150 volts	2500. watts (1000 tubes)

Raytheon Filamentary Subminiature Tubes are distinguished by low power requirements, high efficiency, instant heating, no interface resistance, small size, exceptional ruggedness and long life. They are insensitive to ambient temperature change.

Raytheon *Flat Press*, the *Seal of Reliability*, provides a longer glass-to-metal seal, reduced glass strain, no lead burning, flexible, in-line leads tinned right to the seal. Faster, neater wiring and socketing are assured. Ideal for assembly in printed circuits with dip soldering.

Here are results in actual computer service:

190 tubes after 13,000 hours of operation: no tube failures, all tubes still operating

120 tubes after 11,000 hours, with daily on-off cycles: no failures, all tubes still operating

50 tubes after 16,000 hours: no failures, all operating

10,000 hour factory life tests on these low filament current types normally show no inoperative rejects including no filament or glass failures.

This is RELIABILITY +

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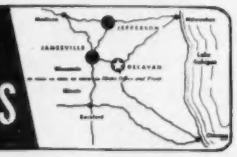
Borg is a highly respected name in its field . . . the manufacture of components for systems. Borg has gained wide recognition as a supplier of electronic components for military and commercial uses.

BORG PLANTS



Borg manufacturing plants are centrally located about 90 miles from Chicago. Easily accessible by highway, rail and air.

WHAT BORG MAKES

Precision Is Our Business. For many years Borg has been prominent in the design and manufacture of precision components for systems.

- **AIRCRAFT INSTRUMENTS**
  Aircraft components, instruments and electronic sub-assemblies.
- **FREQUENCY STANDARDS**
  Crystal controlled oscillator type frequency standards.
- **POTENTIOMETERS**
  Quantity production of Borg MICROPOTS (precision potentiometers) to meet your specifications.
- **MICRODIALS**
  Precision MICRODIALS for single and multi-turn devices. Indexed accuracy of up to one part in 1,000.
- **INSTRUMENT MOTORS**
  Precision motors, synchronous and induction types. Gear trains.

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Borg can assist you in the design and construction of prototypes. Complete facilities for pilot runs and quantity production. Write for Bulletin BED-A50 or call us today.

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Panel Finds Feedback Out Grows The Servo

Feedback control integrates data processing, instrumentation, computation, actuation, and energy processing, listeners learned in June at a panel discussion of the problems and objectives of feedback. This advanced view was the heart of the panel discussion held by The Feedback Control Systems Committee of AIEE during the Summer Meeting of AIEE.

MIT's Gordon Brown started it when he commented that feedback control has matured well beyond its start in the design and analysis of servos. "Now", he continued, "Some professional society will take over; a society that provides professional leadership and support of control engineers and whose work embraces everything from data processing to energy processing. Why not AIEE?" Brown asked.

• **Feedback in steel**—Economic forces—better product and greater productivity—dictate the objectives of feedback in steel, reported Orville Orbom. An alliance of improved data handling with machine controls through a unified language in communication networks that command machine set-up and produce real-time records is the need and the problem. Widespread computing control in heavy manufacturing awaits only its solution. The control system engineer (rare in the steel industry) will have to solve it, he concluded.

• **Need hardware engineers**—C. S. Herwald reversed the field by stating that there are too many systems analysis people in weapons systems engineering, and not enough "dirty-finger" engineers who can put hardware together and make it work. He pointed to these design problems:

▶ Speed; while space coordinates over which information must feed back have lengthened, increased weapon speeds have shortened the time intervals available.

▶ Noisy data; not only does the tactical enemy try to jam signals, but the measurement and transmission equipment may produce noise which is just as harmful as the enemy's. Application of statistical techniques must become a familiar tool of the control engineer.

▶ Man as a monitor; man must be placed in parallel, rather than in series, with control systems. Requires improved display of what the system plans to do.

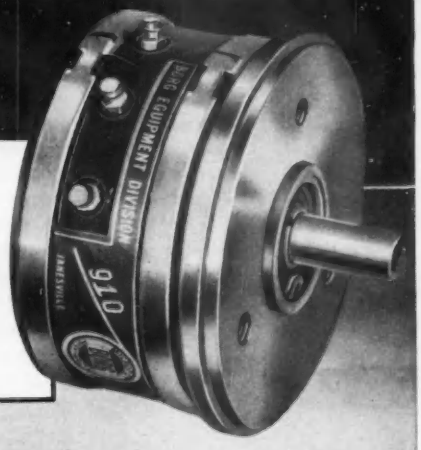
▶ Automatic checkout; foolproof systems which automatically check the working of operational missiles are

PANELISTS	WHERE THEY CARRY FEEDBACK CONTROL
Gordon S. Brown, MIT	education
Orville E. Orbom, Allegheny-Ludlum	steel industry
S. W. Herwald, Westinghouse Air Arm	weapon systems
Harry L. Palmer, GE Specialty Control	industrial control mfg
D. P. Eckman, Case Inst. of Technology	material processing industries
E. M. Grabbe, Ramo-Wooldridge	computer applications
H. E. Chestnut, GE, (Panel Chairman)	general principles

Shock after Shock

THROUGH THE SONIC BARRIER...

BORG MICROPOTS *Can take it!*



NEW!
BORG 910 SINGLE-TURN PRECISION MICROPOT

The new Borg 910 Series Single Turn Micropot retains its high precision characteristics through severe vibration and shock. Borg 910 Micropots were developed from the Borg 900 Series Micropots . . . long preferred in aircraft and electronic fields for accurate, long lived dependability. Let your nearest Borg "Tech-Rep" show you the many advantages offered by the new Borg 910 Series Single Turn Micropot.

WRITE FOR CATALOG SHEET BED A-69 AND NAME OF YOUR NEAREST BORG TECH-REP

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ELECTRONIC – MECHANICAL
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Built by Borg

MOTORS
MICROPOTS
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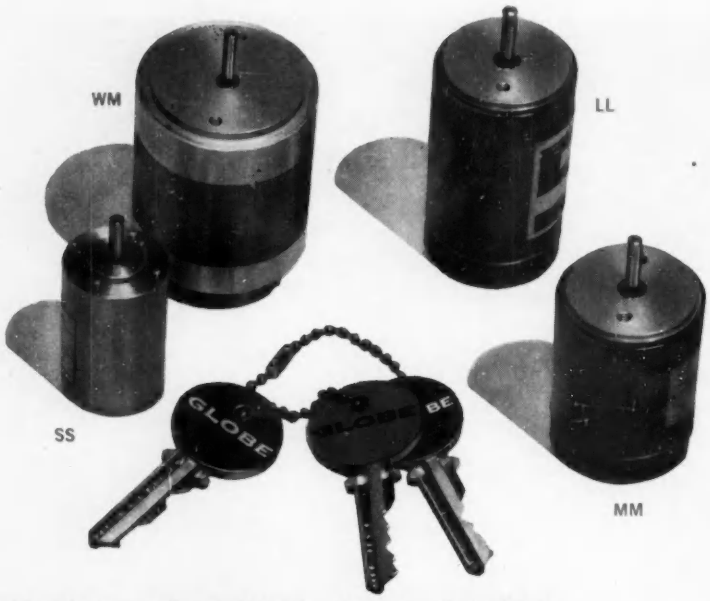

KEY SOURCE FOR SMALL MOTORS

Globe Industries should be your prime source for small, peak performance A.C. and D.C. motors for fundamental reasons. For instance, the four D.C. motors shown are just a beginning—not only can you have them in countless variations, but you can add scores of standard spur or planetary gear ratios. Also, a wide variety of governors, clutches, brakes and filters are available promptly to meet any need you have. All these variables are combined by Globe to give you a motor which outperforms any other motor of comparable size.

An interchangeable standard part inventory, coupled with precision production techniques to match engineering efficiency are specific reasons why you can obtain quality custom built prototypes in 2 to 4 weeks. These same methods shorten lead time on Globe actuators, timers, rate gyros, blowers, servos.

Ask the largest D.C. miniature motor manufacturer first.

Send for your copy of the Globe D.C. motor catalog now.

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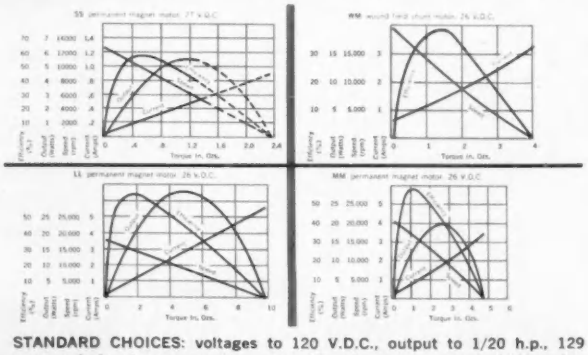


STANDARD CHOICES: voltages to 120 V.D.C., output to 1/20 h.p., 129 spur and planetary gear ratios, geared break away torques to 2500 oz.in., many varieties of governors, clutches, brakes, and filters are available. The graphs appearing above illustrate typical performances.

WHAT'S NEW

now required as integral parts of weapon systems.

Flexible programming; needed for small-lot production of military gear.

• **Need component information**—Whether a "user" or a "maker", the control engineer needs complete information on components under the conditions they will meet in use, Harry Palmer maintained. He explained that because automatic machines will make errors but not mistakes, the designer must know how much backlash, friction, striction, and damping to expect, so that he can minimize machine errors. He pointed out that automatically controlled machines need more-fundamental measurements than do manually controlled machines and gave one example—direct "digital" measurement of absolute position over long traverses.

• **Computing-control for processes**—D. P. Eckman returned to the basic industrial problem, optimum production. The control engineer in a material processing industry has to control systems with hundreds of variables. He now does it with a multitude of independent control loops, but has no way of knowing whether such a system operates with maximum yield or efficiency. Computing-control designed from only a partial description of process kinetics, but with automatic correction of the description, shows promise. Other trends seen by Eckman:

▶ Exponential increase in the use of electronic control in the process industries; the only real drawback today, he said, is lack of a full set of electronic measuring elements.

▶ Solution of problems involving essential non-linearities; chemical process rate may be a function of the n-th power of pressure and the 1/n-th power of temperature. (See article starting on page 197 for complete discussion by Eckman and Lefkowitz.)

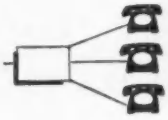
▶ Increasing use of composition analysis measurements will require sampled data control techniques.

Many paths in feedback control today lead to computing control, reported E. M. Grabbe. Analog computers are used in industrial control applications with beneficial results. Digital data loggers featuring continuous calculation of operator guides are available. The digital computer with its high precision, large memory, flexible program, and ability to make logical decisions, effective in military control systems, has much to offer for industrial control. It is on the way. ("See New Digital Computer for Pro-

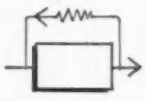
Pacemakers in the technology of our electronic age

Certain discoveries, inventions and developments of Bell Telephone Laboratories have been truly epochal in their effect upon the technology of our time. Each has come out of a single quest—a search for ways to make telephony ever better. But many have opened the way to exciting advances in TV, movies, radio, horology, astronomy. Here are ten of Bell Laboratories' contributions to the modern world.

Electronic amplifier. First high-vacuum electronic amplifier. Made possible long distance telephony and then opened the way to radio broadcasting.



Wave filter. Precisely separates bands of frequencies. Provided major key to economical sharing of the same wires by many voices or radio programs. Indispensable control tool in radio, television and radar.



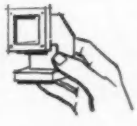
Negative feedback amplifier. Provides distortionless and stable amplification. Made possible the enormous, precisely controlled amplification needed in long distance telephone calls. The principle is now basic in high-quality amplifiers for radio, TV and high-fidelity reproduction.

Quartz crystal. Standard super-accurate quartz crystal oscillator developed for frequency controls in radio telephony. Has also become the standard control for clocks in world's astronomical laboratories.

Coaxial cable system. Hollow tube with a central conductor was developed to transmit hundreds of voices simultaneously. Now also provides long distance carrier for TV in partnership with microwave beams.

Transistor. Tiny solid-state device uses extremely small amounts of power to amplify signals. Makes possible electronic telephone switching and much smaller hearing aids, radios, TV sets and electronic computers.

Dial system "brain and memory." Takes over your call and sees that you are connected in the best and quickest way. Newest example: Direct Distance Dialing from home telephones to any part of the nation.



Waveguide. Hollow conductor transmits high-frequency waves. From this came the "pipe" circuits that are essential to radar and very short-wave radio communications.

Microwaves. Bell Laboratories developed long distance microwave transmission. It operates by focusing radio beams from station to station, carries cross-country telephony and TV.

Radio astronomy. This great new science began in the study of radio interference at Bell Laboratories . . . with the tremendous discovery that radio waves emanate from the stars.

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WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

Numerical Control
brings to industry
an era of important
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to equipment builders
and users
extensive experience
in the development, design
and manufacture of advanced
Numerical Control Systems.

CC numerical control

CONCORD CONTROL, INC., 1282 Soldiers Field Road
Boston

cess Control", p. 41). Its use is sure to change radically the design of future plants and to provide spectacular results in production, Grabbe added.

• **New view for feedback committee**—Such wide-ranging discussions were hardly included in the concept of the charter granted by AIEE to its Feedback Control Committee when it was set up less than a decade ago. But these new concepts and new needs have developed regardless of the charter. It was the unanimous feeling of the panelists, and of most of the listeners, that the activities of the Feedback Control Systems Committee must include them. Whether the committee can embrace them or not, control engineers have.

—W. E. V.

Control Techniques at Cambridge Conference

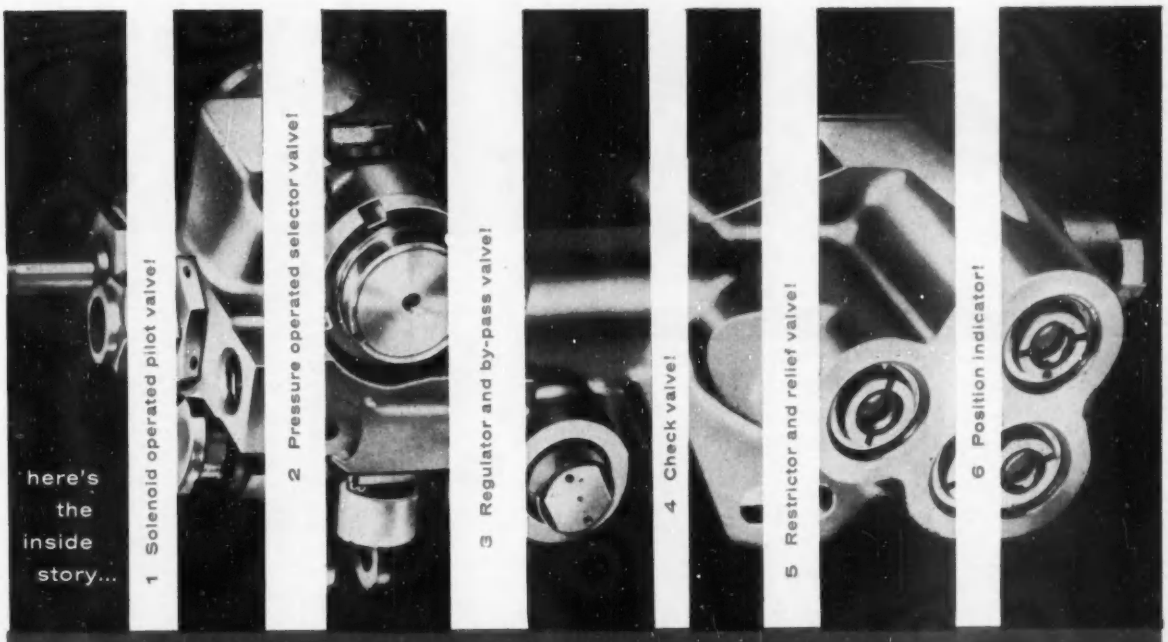
LONDON—

The theme, "Electronics in Automation", and the peaceful academic atmosphere of Kings College, Cambridge, drew some 500 of Britain's leading electronic and radio engineers to the fourth postwar convention organized by the British Institution of Radio Engineers. Interest in the conference (June 26-July 1, with time out for the weekend) was world-wide, with delegates coming from Holland, France, and the Commonwealth, and a strong contingent from the U.S.S.R.

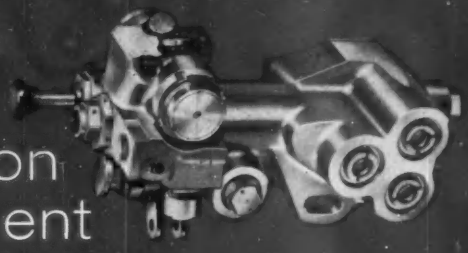
In the four-day period some 40 papers were presented at six sessions: Machine Tool Control, Chemical and Other Processes, Automatic Measurement and Inspection, Simulators, Automation in the Electronic Industry, and Office Machinery and Information Processing.

• **Trend to positioning**—Machine tool control papers excited more than usual interest. Papers by C. Borley of Mullard, by Finden and Horlock of Plessey and by K. J. Coppin of E. K. Cole described actual machines that have been developed. All of these were preset positioning devices, clearly showing a trend in Britain toward this technique rather than continuous contouring. However, the impression gained was one of academic detachment: one felt that more punch would have been given to the discussion had a few machine tool or plant engineers been present, since what took place was talk among the converted.

• **The process control papers**—Papers on chemical and other processes pro-



the new dimension in component packaging!



Weston's Pneumatic Actuator Control Valve Package Combines 6 Components in a Single 6.4 lb. Unit!

While controlling the pneumatic actuator, this weight and space saving valve also provides for snubbing pressure at the opposite end of the stroke. It affords extremely fast operation (maximum at .04 seconds) and low leakage (10 cubic inches per hour). The selector valve is non-interflow and detented to maintain position. If you have a weight and space problem, let Weston's team of specialized package engineers solve your specific application.

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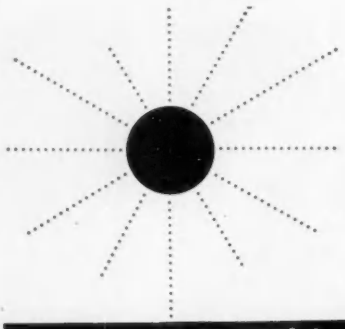

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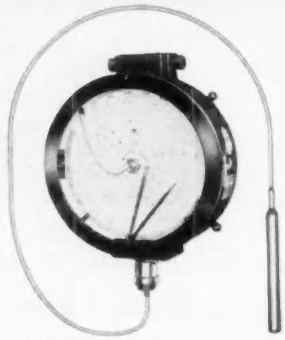

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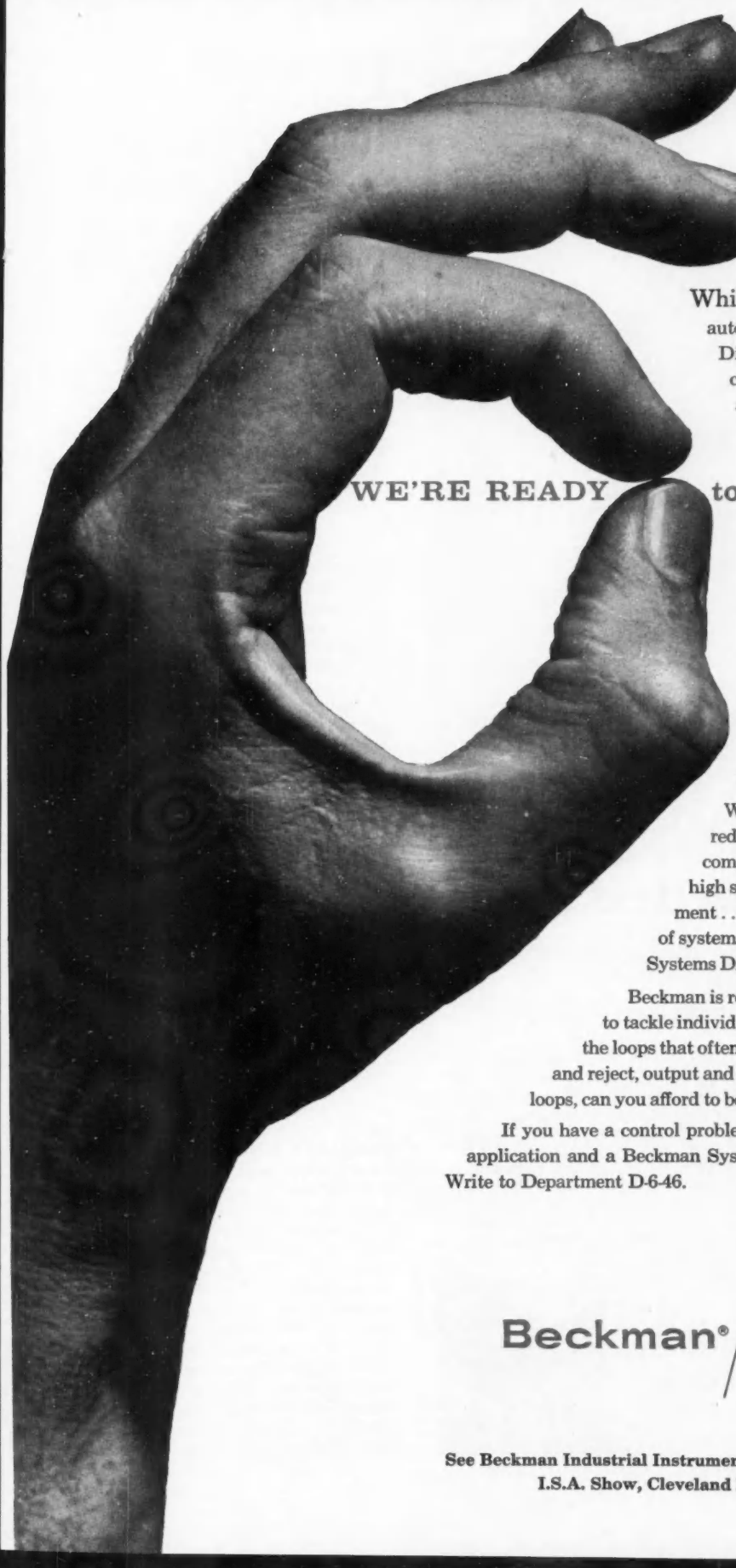
WHAT'S NEW

voked lively discussion in and out of the sessions. "Process Control Systems" by J. Keating and P. Slee of Shell-B.P. contained the more advanced thoughts on continuous computer monitoring and analysis of plant performance, studies that are still in the theoretical stage. J. Halsall of ICI discussed some novel circuits for phase-sensitive rectifiers suitable as current generators for force balance system feedback.

One session was devoted to a discussion of radio assay tracer techniques and industrial applications of ac polography. The two most important contributions in this particular session were the papers by Dr. Rosenbrock on "Approximate Relations Between Transient and Frequency Response" and by Z. Czajkowski on "An Electronic Three-Term Controller". Dr. Rosenbrock's was an extension of his earlier work on a quick, simple method, using special cursors, for the determination of transient response from frequency response and vice versa.

• **Interacting vs. noninteracting systems**—The paper on three-term electronic controllers (the result of work by Czajkowski under the direction of Dr. d'Ombrain at the Battersea Polytechnic) described an interesting way of generating the three functions independently to give a noninteracting system. Although, its six tubes made this a research or laboratory tool rather than industrial equipment, it sparked a lot of comment, both in and out of the session, on the merits of interacting and noninteracting systems. And it recalled David Boyd's paper, presented last year at Heidelberg, on "The Importance of Minimizing Hysteresis in a Process Temperature Controller", because Boyd's theory of dead zones renders it impossible to utilize fully derivative action. Two schools of thought were in evidence at Cambridge: one school feels that Boyd's assumptions need verifying and the other claims that they justify the entirely electronic system inherently free of hysteresis (several control firms in the U. K. are working hard on this idea, some with trial equipment in the field).

• **Analog vs. digital**—Another highlight for the control engineer was the last half of the simulator session. Here the controversial question of analog vs. digital computers was raised by R. J. Gompters of English Electric in his paper "Computing Applications Where Analog Methods are Superior to Digital". Gomperts' main argu-



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automatic control, Beckman Systems Division is "closing loops" the country over . . . in steel mills, in aircraft and textile plants, in the petrochemical industries. Not yet

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fully automatic *manless* plants – but *manless* installations, production lines, and processes. From wind tunnels to paper mills, Beckman has provided the systems engineering experience and the advanced hardware necessary to convert manual and semi-automatic operations to the fully automatic efficiency required in the new industrial era.

With reliable data processing and data reduction systems . . . with digital timing, computing, and recording equipment . . . with high speed digital and analog control equipment . . . with a firm, sure hand in the entire field of systems and applications engineering – Beckman Systems Division can close loops for you *now*.

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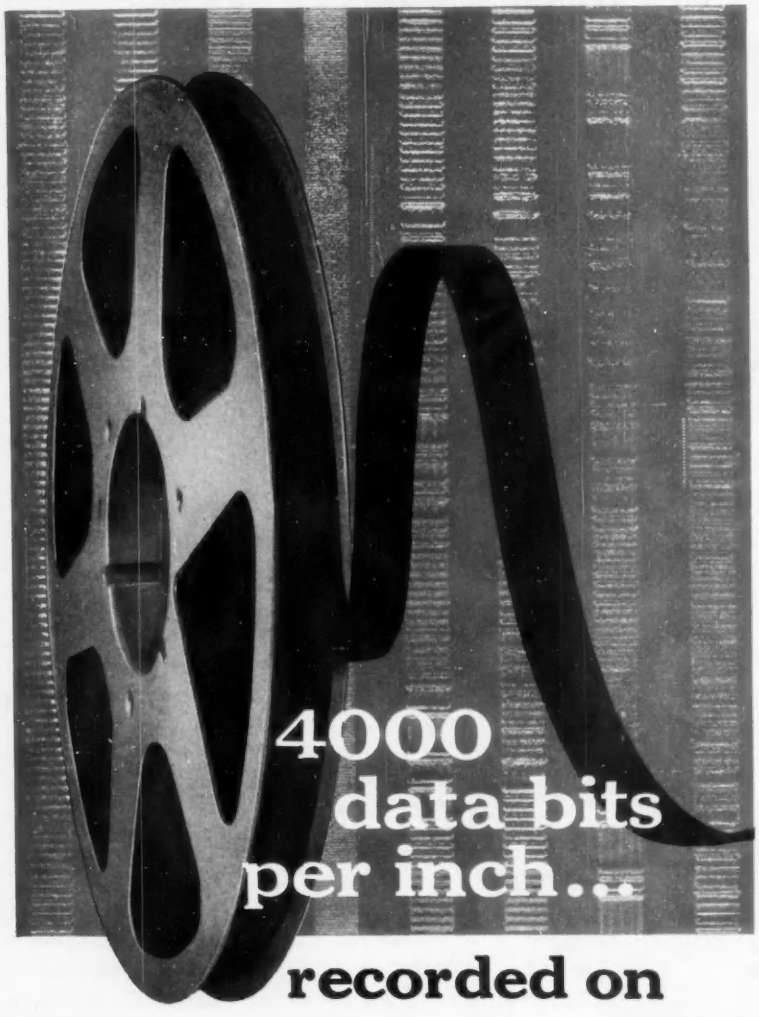
Microphotograph of pulse recording on Soundcraft Instrumentation Tape



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WHAT'S NEW

ment: the use of an analog method to solve engineering problems may be less accurate than the digital approach, but it is adequate. And it's far less complex.

In the same session an extremely competent paper on "The Application of Analog Computer Techniques to the Design of Aero Engine Control Systems" by Jeffrey of Elliott Bros. and H. Saville of Armstrong-Siddeley, Ltd., set the audience thinking on the complexity of the design work needed in what was a simple application of a closed loop with two subsidiary loops. Another important presentation was the one by J. Henderson (of Birmingham University) on the use of cross-correlation between input and output signals as a method of determining system transfer functions.

In the office machinery papers the highlight was R. J. Froggatt's on "Logical Design of a Computer for Business Uses", which confirmed a rumor current in industry that EMI Electronics, Ltd., was entering the digital business computer field. This, the first published information, shows its machine to be serial-operated at a clock rate of 115 kc. with a word length of 36 digits. Input data is from standard punched cards, and the ouput line printer is the Power-Samas 300 line-a-minute Samastronic. The first of these is due to go into service in the fall for production control at the Austin automobile factory.

–D. B.

Russians Plan N-S Orbit for Satellite

Russia will place its earth satellite in a north-south orbit at a small angle to the meridian, Prof. Boris Petrov of the Soviet Academy of Sciences told a three-day international symposium on high altitude and satellite rockets at Cranfield, England, in July.

The Russians apparently are confident that their propulsion system will provide sufficient velocity to overcome the disadvantages of a north-south orbit. U.S. plans for the Project Vanguard satellite call for an orbit as close as practical to an east-west plane, in order to take advantage of the earth's rotational velocity.

• **Velocity gift**–Reasons for the American choice were explained to the symposium by Milton Rosen, technical director for Project Vanguard. "This earth rotational velocity is a gift, so

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WIV @ 0.1mA	up to 200V
Forward Voltage @ 4mA	less than 1.5V
Recovery (modified IBM "Y" test)	400K ohms (min.) in one μsec. when switched from 30mA forward to −35V reverse.
Reverse Current @ 25°C	as low as 1μA @ −175V
Reverse Current @ 100°C	as low as 100μA @ −175V
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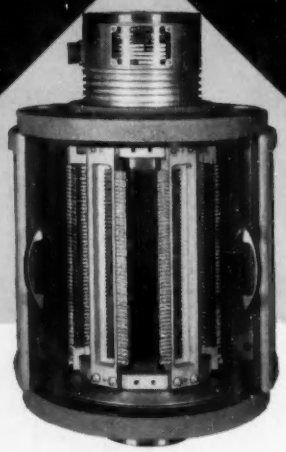

The new 512A Bryant general purpose magnetic storage drum is built to meet the exacting requirements of all permanent storage problems, yet is versatile enough to be used as a laboratory instrument. It is the result of 25 years' experience in designing and producing high-speed precision spindles. These standard 5" dia. x 12" long drums are stocked for immediate shipment at a price that reflects quantity manufacture, far below the cost of customer-designed drums.

Features:

- Guaranteed accuracy of drum run-out, .00010" T. I. R. or less.
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to speak, of which the launching vehicle may take advantage by favorable choice of launching site and direction," he said. "Obviously the best condition would be to launch due east at the equator, in which case the velocity gift would be 1,515 ft/sec".

• **A compromise**—Rosen pointed out that orbit requirements involve a balance between velocity performance and guidance precision—the more velocity available, the less precision.

"The Vanguard approach," he said, "has been to maintain a substantial excess velocity capability and to hold the precision of guidance to that acceptable for a minimum performance."

Experts say that firing from a site in the Soviet Union in any event would provide less of a rotational contribution. Apparently the Russians have decided to pass up the east-west advantage in favor of a north-south orbit which will give much greater coverage of the earth's surface.

It thus will be possible to observe the Russian satellite from all parts of the earth with the exception of areas of the Arctic and Antarctic.

• **Other Russian IGY activities**—Petrov said no date had been fixed yet for the first Russian launching, and that the number of attempts to be made will depend on initial success in achieving an orbit.

Petrov headed a three-man Russian delegation to the meeting. He also outlined Soviet plans for firing a total of 125 high-altitude rockets during the International Geophysical year.

Operation Far Side: A New Approach

Scientists at Aeroneutronic Systems, Inc., Ford Motor Company's west coast subsidiary, have come up with a new approach to beat the friction problem caused by the high drag coefficient of the lower atmosphere in rocket firings. The answer: fire a 1,900 pound rocket at 100,000 ft from the largest balloon ever launched.

According to Dr. Ernst H. Krause, Vice President of Aeroneutronic's, the four stage solid propellant rocket vehicle (nicknamed far side which wrongly led some people to guess the project was an attempt to photograph the far side of the moon) will carry a small 3½ pound, highly complex package of scientific instrumentation at a top speed of over 17,000 mph. Purpose of the test is to investigate atmospheric and space phenomena at extremely high altitudes.

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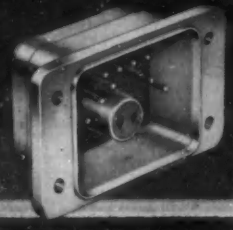
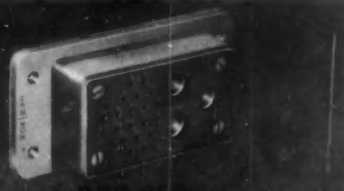
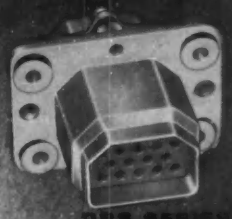




Cannon offers you more than 18 different basic designs in rack panel-chassis connectors... designed with all the latest features to give you accurate alignment, easy mating, proper connection, and interfacial sealing where desired.



Select the connector you want in standard, miniature, or sub-miniature sizes... for standard circuitry or printed circuitry. Up to 156 contacts... and a great number of combinations of contacts for control, audio, thermocouple, co-ax, twin-ax, and pneumatic connections. In single- or double-gang. Some with shells, some without... all ruggedly constructed to take the many "in" and "out" operations of rack, panel, chassis, and sub-assembly applications. Special moisture-proof types. Standby units featuring gold-plated contacts to withstand deterioration and corrosion.

For an interesting discussion of the broad subject of "Reliability," write for Cannon Bulletin R-1.

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CENTURY MODEL 409D RECORDING OSCILLOGRAPH

Numerous agencies engaged in the manufacture and evaluation of missiles have turned to the Century Model 409D Recording Oscillograph as a reliable means of collecting missile performance and control data.

On-board mounting eliminates the necessity for the costly and often not reliable RF link.

The ruggedness and reliability of this 12-channel oscillograph have been demonstrated many times. One agency reports having recovered 42 satisfactory record rolls out of 43 firings. Another, using special mounting configuration, reports recording at 60 G's without damage.

This 13 lb. instrument is compact enough to be installed in most missiles and all electrical connections including remote control are accomplished through a single multi-pin AN connector.

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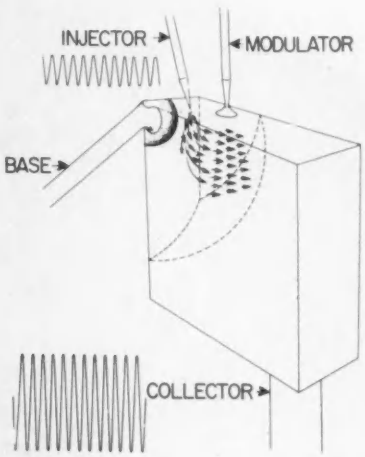
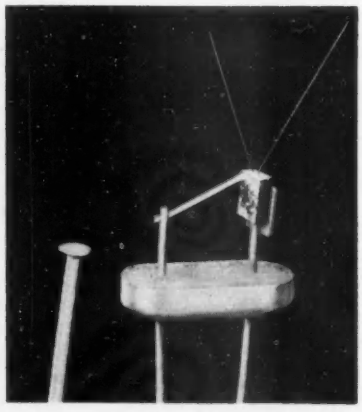
WHAT'S NEW



Spacistor

. . . pushes back frequency limits on semiconductors

For those attending the sessions of the July semiconductor meeting sponsored jointly by AIEE and IRE, Raytheon Mfg. Co. had unexpected news: Raytheon scientists have developed a new semiconductor device that promises two major advantages over today's best transistors. Dr. Herman Statz told the Boulder, Col., conclave he was sure that the new "Spacistor" will amplify at frequencies up to 10,000 mc. and will operate at temperatures up to 500 deg C. And he saw a variety of potential applica-

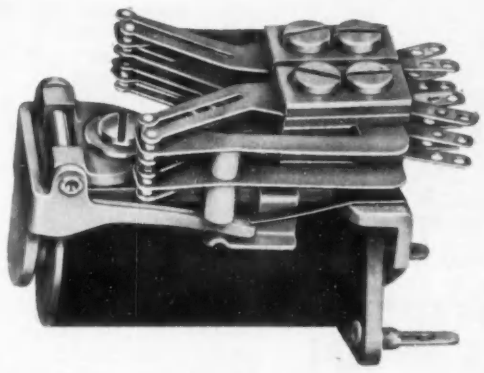


Magnified view of new semiconductor device (compared to a common straight pin at left) shows main parts: whisker-like ejector and modulator, base and collector. For further size comparison, Spacistor is attached to boat-shaped transistor mount.

ALLIED'S *New*

General Purpose Relay* for d-c Operation

Long life, stability and high reliability are the features of this new general purpose relay. Allied's type GK relay uses twin palladium contacts with bifurcated stationary contact arms. Designed for a wide variety of Industrial and Military applications, Allied's type GK relay has a capacity of 20 springs which can be assembled in a variety of combinations of A, B, C and D contact forms.



Type GK Relay

Here are the facts:

Operating Voltage:
up to 220 volts d-c

Contact Rating:
up to 4 amperes at 150 watts

Temperature Range:
up to −55°C to +85°C

Vibration:
up to 10 to 55 cps at .062 inch double amplitude

Operating Shock:
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* *For complete details send for Allied's GK catalog sheet.*

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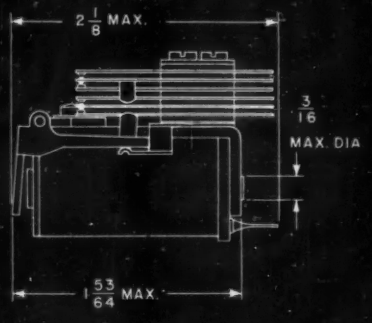

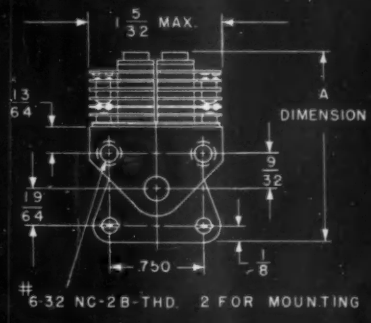

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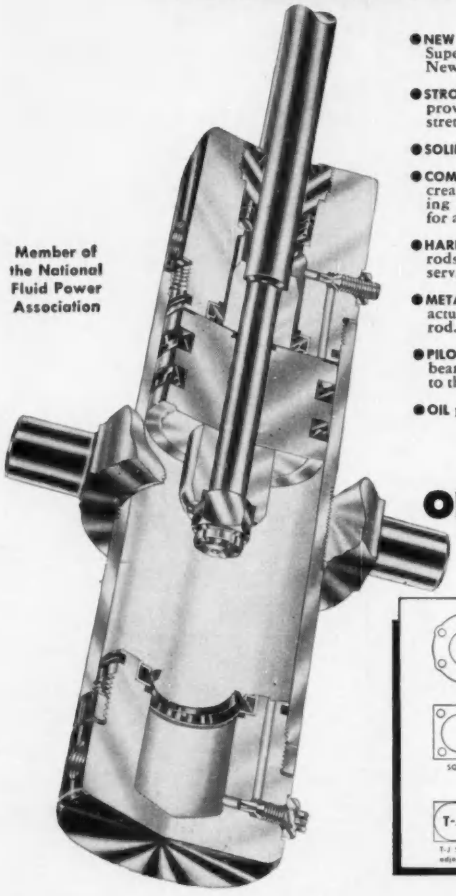

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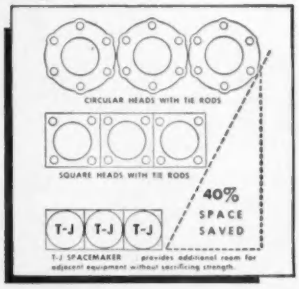

You *save 40% space* when you switch from outmoded tie rod cylinders to the T-J Spacemaker! It's stronger, too! Fits right into automation programs in countless plants. Delivers top performance and dependability with a big *plus* in advanced features. Wide range of styles, capacities . . . reduces man-hours and costs in all kinds of push-pull-lift jobs. Off-shelf delivery in 64,000 combinations!

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tions in radar, guided-missile control systems and communications.

But the news was not all good. For those with immediate problems demanding high frequency and high temperature transistors, Raytheon could offer little help. Although a team of researchers have been developing the spacistor for two years, the company felt it would need three to five more years of R&D before Spacistors would be commercially available.

• **An electric field**—Dr. Statz was able to describe how the new device differs from a typical transistor. The big difference is an electric field. In the Spacistor (see drawing), a voltage is applied between the base and the collector, producing a high electric field and virtually no current. Another voltage, applied to a fine wire called the injector, causes electrons to enter the region of the electric field. From here they flow rapidly to the collector contact. The resultant current is modulated by the application of a signal to another whisker-sized wire called the modulator. Since the modulator draws only a negligible current while causing the current between injector and collector to fluctuate, amplification results.

The Raytheon scientist also pointed out that the new device retains many transistor advantages. It operates on very low power, it can be tightly packaged, and it uses no strategic materials.

COMPUTER NOTES

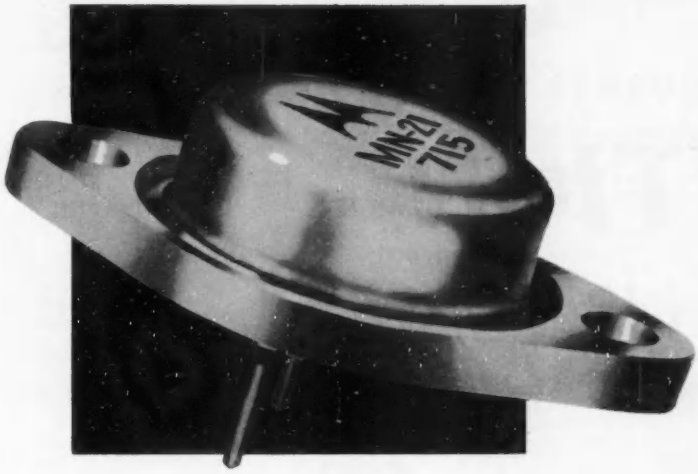
First electronic data processing equipment installed in the textile industry is an IBM 305 Ramac (Random Access Method of Accounting and Control), which will be used by United Merchants & Mfg., Inc., to solve merchandising problems.

•

IBM has installed a transistorized pilot model of the IBM 738 high-speed memory unit at the Rand Corp. in Santa Monica, Calif. The memory, IBM's first transistorized computer component, doubles the effectiveness of an IBM 704 computer by quadrupling maximum storage—increasing capacity to 32,768 six-letter words. IBM reports access time to be 12 millionths sec.

•

U. S. Navy's Bureau of Ships has bought a UNIVAC-LARC to help design nuclear reactors in shipboard power plants. The $3,500,000 computer will do more than 100,000 multiplications each second.



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- Reliable Operation With High Junction Temperatures
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- Operation of high-speed printers and other electro-mechanical output devices
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Wherever high-voltage power transistors are required!

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V_{CB} MIN.	V_{CE} BASE OPEN	V_{CS} $I_C = 2A.$ $I_B = .2A.$	B $I_C = 1A.$ $V_C = 4V.$	G_{FE} MHOS	SWITCHING TIME	THERMAL RESISTANCE
80 V.	65 V.	.6 V.	55	1.2	50u SEC.	1 °C/WATT

Collector rating of 40 Watts with mounting base at 30°C.

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Auditorium, Cleveland, Ohio, Sept. 9-13, 1957

SEE! The amazing new "AUTOMATIC CHEMIST"!

"The most dramatic exhibit in analysis instrumentation at the recent British Instruments, Electronics & Automation Exhibition in London". CONTROL ENGINEERING

This Titromatic Analyzer, containing an array of glass vessels controlled by automatic taps and a control unit for sequencing the titration, connects to the main plant stream. It releases up to three chemists for other work, quickly paying for itself. Don't miss this one!

ASK FOR BULLETIN EIL-34!

SEE! The new IRC-Robertshaw Pressure Scanning System

This new combination pressure-temperature scanner utilizes a new low-cost pressure transducer. It's too hot to describe here, but be sure to see it in action at the booth!

ASK FOR BULLETIN F-340!

SEE! The new Robertshaw VIBRASWITCH Malfunction Detector

New principle is used by this invaluable unit to stop costly equipment damage by detecting damaging malfunctions. See it demonstrated right in the booth. Get all the details on how it can protect your rotating, reciprocating and other equipment.

ASK FOR BULLETIN 600-5!

SEE! The new Rogers Moisture Controller

with the new vibratory feed cell. Continuously monitors and controls moisture content of granular material. Prevents jam-ups . . . gives superior performance. See it in action on polyvinyl chips!

ASK FOR BULLETIN RMC!

SEE! The new In-Line Liquid Conductivity Cell

New . . . for high temperature and pressure applications—up to 1000°F. without compensation, and up to 250 psi pressure. Eliminates the need for sample coolers on many applications.

ASK FOR BULLETIN IDS-004!

SEE! The new Land Radiation Pyrometer

and the Land Surface Pyrometer in dramatic demonstrations right in the booth . . . plus the world's most superior line of pyrometer mounting accessories, temperature sensing elements, recording and controlling instruments

ASK FOR BULLETIN FL-197!

I am unable to attend the Show. Please send me the technical bulletins on Robertshaw Instruments as checked below:

- ☐ EIL-34
- ☐ 600-5
- ☐ IDS-004
- ☐ F-340
- ☐ RMC
- ☐ FL-197
- ☐ F-104
- ☐ IDS85-2
- ☐ WK-B221
- ☐ EIL-3311
- ☐ Details on new metal-ceramic sealing technique.

Name _____
Firm _____
Address _____
City _____ Zone _____ State _____

Robertshaw-Fulton CONTROLS COMPANY

INSTRUMENT DIVISION
Dept. S, 2920 N. 4th St., Philadelphia 33, Penna.

SEE! Samples of high temperature, high pressure metal-ceramic seals produced by a new Robertshaw technique. Let's discuss your nuclear power, jet engine, rocket, missile and other high temperature applications at the ISA Show . . . or mail the coupon!

Don't miss
INSTRUMENTS IN
ACTION
at
BOOTH 1346

SEE! The new P-E-P Transmission System
It will be in actual operation! Completely new in concept, this system promises to revolutionize pneumatic transmission instrumentation. You'll have to see it to believe it!
ASK FOR BULLETIN IDSBS-2!

SEE! Fielden Level Controls
in *action* on both liquids and granular material. Be sure to get the new Level Controls Brochure compiled by Fielden Level Control specialists.
ASK FOR BULLETIN F-104!

SEE! The new EIL Model 33, Vibrating Condenser Electrometer
This instrument has a pH measuring unit with which full scale readings of 0.1 pH are attained, plus a current and resistance measuring unit. Look it over and let's discuss it in detail.
ASK FOR BULLETIN EIL-3311!

SEE! The new Wayne Kerr B 221 Bridge
and accessories for laboratory measurement of dielectric constant conductivity, permativity and boundary layer impedance.
ASK FOR BULLETIN WK-B221!

AROUND THE BUSINESS LOOP

Subcontracting, GE Style

How a big company, deep in military and industrial work, goes about farming out specialty control jobs, and what the results are for itself and its vendors.

Last June General Electric Co. revealed that small business concerns were going to share in a $158-million missile contract to the tune of more than 50 percent. But "revealed" might not be exactly the right word, because there was little in the way of a revelation in the announcement: it is standard procedure for GE to let small business handle specific phases of a control assignment on which it does the overall systems engineering. It's a philosophy that's far from an altruistic approach.

Take the contract just mentioned. It concerned the development of nose cones for the Atlas intercontinental and Thor intermediate ballistic missiles, two big components in the AF ballistic missile program, which is under the direction of the Air Research & Development Command. The nose cone for these missiles, the part that contains the warhead, must re-enter the earth's atmosphere from extreme altitudes at tremendous velocities. All this means control specialists and special control skills, and some of these GE doesn't have.

But that isn't to say it wants them. It's pretty expensive keeping highly-paid production and R&D men around when they're not being used constantly. And—something that's far more important—it's not good for business, because there is a give and take, an interchange in business, just as there is in other kinds of successful relationships, and GE knows this.

• **Make or buy?**—However, there is a phrase in the business world that carries more meaning than building relationships, and this is "make or buy". GE has its own point of view about this. Talk to Herbert L. Schnell, a GE consultant on manufacturing and factory equipment subcontracting in the Materials Service Dept., who'll spell out GE's thinking on make or buy this way: "GE will take the big risks and the big opportunities which challenge us, and break them up into the greatest practical number and variety of small jobs for our subcontractors."

This is the give-and-take part of the philosophy. The economy part is just as logical, particularly because it's got to do with specific figures. In 1955, says Schnell, GE could have called on 40,000 small companies for help in fulfilling contracts; today that number has increased to 42,000, and it's constantly growing. With all these companies eager to do business with GE and with many of them, small though they are, better equipped in specific control areas than GE, it is often more reasonable to "buy" parts (have them made under a subcontract) than make them. And that's just what GE frequently does.

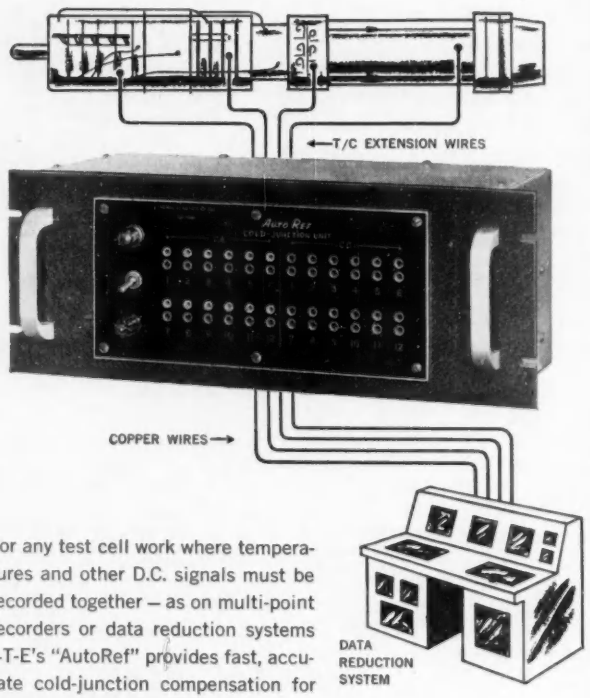
Decisions, of course, must be made on making or buying, and that means evaluations. And when it comes to evaluations, GE ceases to be a large company and becomes a group of small ones. In other words, every one of GE's 159 plants are autonomous in the make-or-buy department: when the individual plant manager deems it economical from the dollar-volume standpoint, that's when the make-or-buy philosophy is applied. As Schnell says, "Make or buy evaluations are essentially necessary in a highly competitive era where science, inventions, and engineering are guarantying that methods and processes in use today will become obsolete tomorrow or a year from now. This competition is the driving force behind the wheels of progress." That last sentence is loaded with cliches, but GE's not worried: if the cliches work, that's all that counts.

• **600 subcontractors**—An examination of the nose-cone contract mentioned above yields additional facts on GE's procedures in subcontracting control work. The share of the total dollar volume going to small businesses involves both materials and services, and adds up to more than $80 million, which is somewhat over the half-way point in the contract's total $158-million value. Says George F. Metcalf, general manager of the GE Missile & Ordnance Systems Dept., "Currently, we are utilizing the services of over 600 suppliers and subcontractors on the nose-cone project, 85 percent of

T-E's *AUTOREF* Provides

Cold Junction Compensation For Many Thermocouples

Ideal For Data Reduction Systems



For any test cell work where temperatures and other D.C. signals must be recorded together – as on multi-point recorders or data reduction systems –T-E's "AutoRef" provides fast, accurate cold-junction compensation for the thermocouple circuits. In one, compact unit it gives you constant, pre-determined, cold-junction reference for many thermocouples – actually up to several hundred. Typically, cold-junction temperatures can be controlled to within ±1°F. over a wide range of ambient temperatures.

Besides its accuracy, the "AutoRef" offers tremendous convenience – saving both time and effort. Designed for panel rack mounting, it can be introduced anywhere in the thermocouple circuit – no matter where thermocouples and instruments are located. Whenever temperatures, pressures, flow-rates and other electrical and mechanical conditions are being recorded simultaneously, the "AutoRef" does away with the need for maintaining ice baths or making laborious correlations. It is available for all standard thermocouple calibrations.

Write for Bulletin 81-B

Thermo Electric Co., Inc.
SADDLE BROOK, NEW JERSEY
In Canada — THERMO ELECTRIC (Canada) Ltd., Brampton, Ontario

WHAT'S NEW

whom represent 'small business' as defined by the military services."

He adds, "The extremely tight time schedule demanded by the country's most urgent defense program and the importance of the nose cone to that program, require that both small business and larger firms contribute their efforts in technical areas where each can perform with maximum efficiency. Thus, by utilizing the unique talents of small, specialized firms for development of components and subsystems, General Electric can concentrate on the critical research programs and on the overall system engineering projects which require vast resources of extensive manpower and facilities found only in large, diversified companies."

A team of 2,000 under Manager R. W. McFall is working full-time on research, systems engineering, design engineering, and development manufacturing for the nose cone. Within this section, top company managers plan the programs, organize the development teams, integrate the operations, and constantly measure progress. One major reason for this planning, organizing, integrating, and measuring is to make sure that the 600 subcontractors don't fall behind and that their product is up to standard.

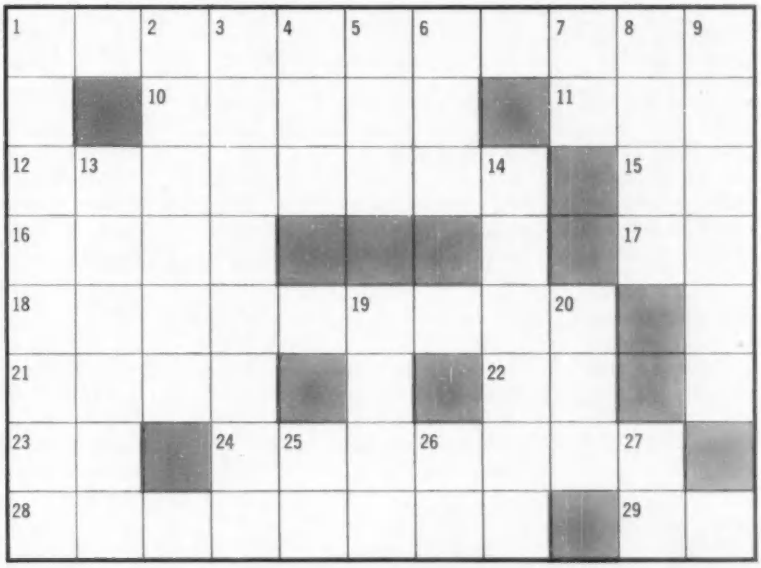
• **Price, quality, service**—It's pretty obvious that a few good subcontracts can take a company out of the subcontracting bracket and put it on the road to becoming the size of GE itself. It happens all the time to those companies that furnish the right price, the right quality, and the right service, because the opportunities are there. As Metcalf says, "Subcontractors will receive from 39 to 43 percent of the dollar volume from the latest research and development contracts we have received from Picatinny Arsenal of the Army Ordnance Corp. This percentage compares favorably with the 40 percent for pilot production and the 44 percent for quantity production now being subcontracted on other Army Ordnance contracts.

"On one research and development contract alone," he continues, "our department will subcontract over $2 million. The magnitude of these awards by one department of one company on one R&D contract is an indication of the opportunities available to small business in the extensive R&D programs being undertaken for the military services on an industry-wide basis."

Schnell cites the case of Thompson Products, Inc., of Cleveland, which

(Continued on page 300)

There once was an ad that didn't want to have cross words with its readers, yet it wanted to be noticed—realizing that engineers enjoyed problems, it decided to be puzzling.
MORAL: If you can't convince 'em, confuse 'em.



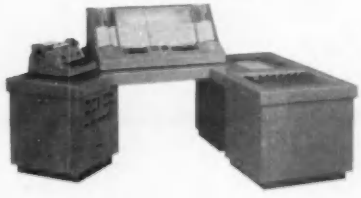
ACROSS

1 Scientific study of methods of control and communication common to living organisms and machines... also title of book most commonly quoted by particularly pedantic engineers.
10 A Hollywood idol by any other name would be a well-known B/L product for the reading and analysis of oscillographic record.
11 To dally with the mockup.
12 Subject to a radical change by the application of a slight force, or horsepower at rest.
15 Didactic symbolism (abbrev.) or in chemistry, dysprosium
16 Part of name of the old alma mammy
17 Having dined
18 Portion of non-solidifying oils (slightly old spelling)
21 Abbrev. for beaucoup rupees (we had to dig for this one)
22 Cheery greeting to chief project engineer at 8:30 a.m.
23 Two in binary
24 Precious metal similar to toothpaste ingredient
28 $1/10$ of a millimicron
29 When you've got to... you've just got to...

DOWN

1 Standard of judgment, usually varying in great degrees between management, engineering and purchasing
2 B/L product used in analysis of frame by frame film records
3 Yet to be designed into automatic computers
4 Publisher of "valve" handbook
5 Capture, as in recruitment
6 Brooklyn lubricant
7 Personal pronoun often used to describe latest prototype
8 The intimate language of a computer
9 A string of black boxes plus interconnecting cables
13 A wrestling hold learned by engineering department secretaries
14 Two-word phrase describing attitudes of personnel managers toward engineers
19 Beats one of a kind
20 World's largest institution of higher learning
25 Direction of a woman driver with her left hand held straight out (abbrev.)
26 A solution to postponed work
27 Abbrev. for a small quantity; also a sometimes mobile object

Another in a series of adsmanship parables provided as a public service by Benson-Lehner Corporation. For the solution to the above puzzle, or some startling information about a revolutionary new computer output device, write for our new Electroplotter S brochure to:



benson-lehner *corporation*
11930 Olympic Boulevard, Los Angeles 64, California

OFFICES: LOS ANGELES; SUMMIT, N.J.; WASHINGTON, D.C.; DAYTON, OHIO; LONDON; PARIS AND OTTAWA.
Service centers in 15 cities throughout the world.
For a permanent file of this series write to Benson-Lehner, Dept. S2 for your Adsmanship Handbook folder.

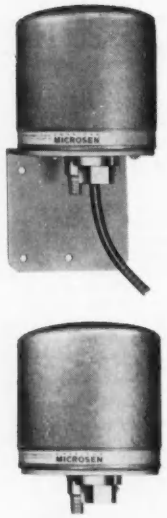
LOOK WHAT

'American-Microsen' Electronic

ELECTRONIC TRANSMITTERS

"Complete" is the word for the line of 'American-Microsen' Transmitters. You can select units for pressures up to 50,000 psi and all temperature ranges, as well as for flow, level, pH and all the electrical measurements.

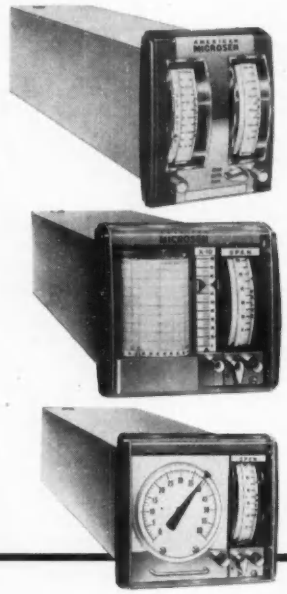
These instruments can transmit up to 30 miles in a split second, and the dc signal is most accurate and trouble free. They are compatible with practically all data logging and computer systems and extremely easy to install and maintain.



ELECTRONIC CONTROLLERS

. . . and here's the new 'American-Microsen' Controller. You have a choice of three plug-in units – a vertical scale indicating controller, a recording controller, and a round-scale indicating controller that can be interchanged with the recording type in seconds.

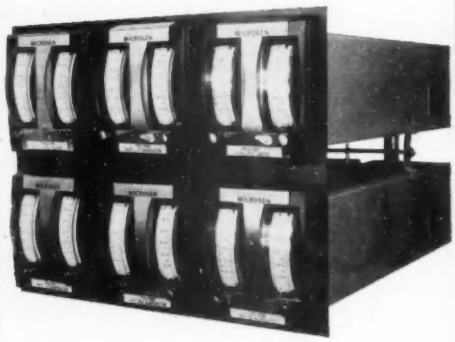
All components are in a single housing. Equally important, the controller is transistorized for greatest reliability and long service life. All control modes – proportional, rate, reset, cascade, etc. –are available.



MULTI-UNIT GROUPINGS

Now, here's a new idea that helps cut the cost of your panels and even your control rooms. You can "cluster" a whole group of controllers and recorders in a single unit. The group mounts on a standard relay rack and occupies an absolute minimum of panel space.

There's no clutter of wires and pipes behind the panel – with the 'American-Microsen' System! Even with the controllers mounted so close, the installation is clean and easy to service.



MANNING,

MAXWELL MANNING M&M E.MOORE INC. TRADE MARK

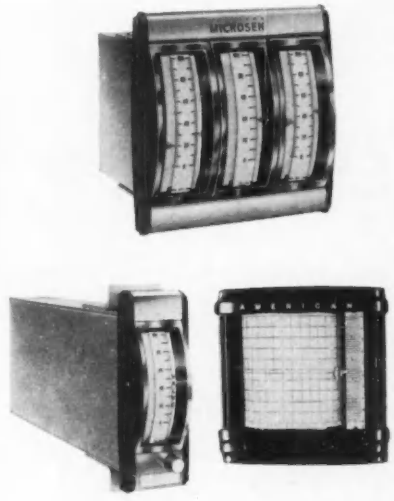
'AMERICAN-MICROSEN' . . . the all-electronic system of miniature-type instruments that provides the ultimate in process control, product quality and total economy.

YOU GET in the
Transmission and Control System

VERSATILE . . . INTERCHANGEABLE

Take a look at this vertical scale indicator. It can have one or two separate pointers on a single scale and comes in multi-unit enclosures to take up the least possible space on the panel.

Talk about a neat package – this slim manual valve operating station is it! It uses the same components as the controllers. You can be sure the 'American-Microsen' Electronic Transmission and Control System offers a whale of a lot in interchangeability.

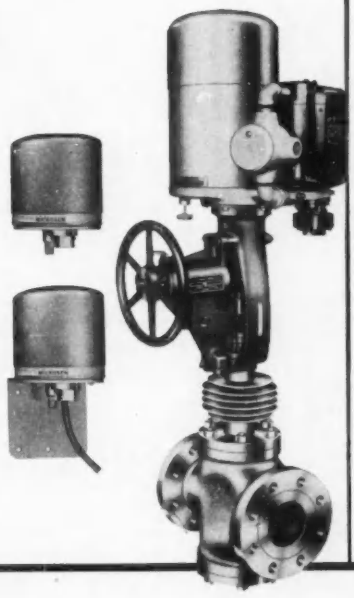


TRANSDUCERS . . . VALVE OPERATORS

You can operate pneumatic diaphragm valves with these transducers – or you can use the self-contained electro-hydraulic valve operator and eliminate all air.

The electro-pneumatic relay has a built-in booster to give a capacity of 8 cfm. That's the highest of any!

The 'American-Microsen' electro-hydraulic valve operator will stroke all valves up to 16 inch and larger. It delivers up to 3250 lbs. of thrust. *No other in its price range compares with that!*



SEE

OUR EXHIBIT AT THE

I.S.A. SHOW

Convince yourself! See the 'American-Microsen' Instruments at the ISA Instrument-Automation Conference and Exhibit. Visit Booths 932-936-938-940 at the Cleveland Auditorium, Cleveland, Ohio – September 9th through 13th.

If you can't make the ISA Show, write for literature and ask a sales engineer from our nearby district office to call and explain the advantages of 'American-Microsen' Instruments for measurement, transmission and control. You will not be obligated in any way.

MAXWELL & MOORE, INC.

INDUSTRIAL CONTROLS DIVISION

Stratford, Connecticut

MAKERS OF 'AMERICAN-MICROSEN' ELECTRONIC INSTRUMENTS FOR MEASUREMENT, TRANSMISSION AND CONTROL

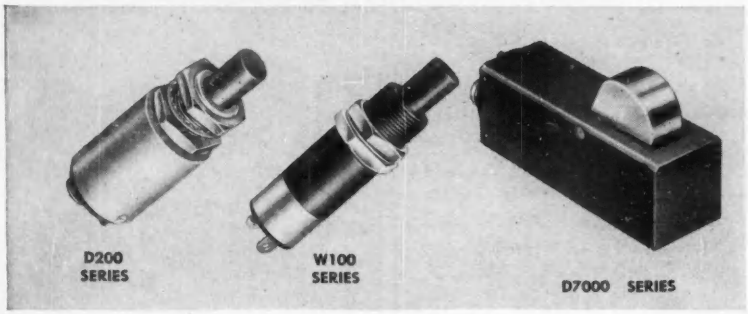
HETHERINGTON

SWITCHES • INDICATOR LIGHTS • SPECIAL ASSEMBLIES

ENGINEERING NEWS #6

LIMIT SWITCHES

for Heavy Current Jobs



For heavy-duty limit or positioning applications, Hetherington offers a variety of special switches with ratings from 10 to 35 amperes.

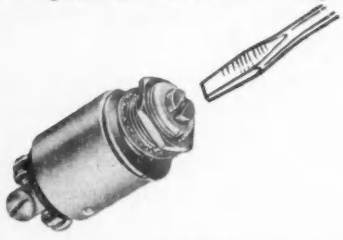
Pushbutton types, such as the slim, 9/16″ diameter "W100" Series or the 35-amp "D200" Series, feature short, unusually sturdy plungers that afford positive direct operation in minimum space. Threaded aluminum bushings provide easy mounting and positioning.

Where switches must operate against sliding surfaces, the cam-operated "D7000" Series proves ideal for many applications. Flush mounting, and only 2-27/64″ long by 3/4″ square, this small switch has a polished stainless steel cam which retracts within 1/32″ of the switch body. Over-travel is 9/32″ minimum.

Like most Hetherington products, Limit Switches use Hetherington's tease-proof, double-break, snap-action mechanism. A variety of single-pole contact arrangements are available on each type. Switch mechanisms are effectively sealed against dust and moisture by integral anodized aluminum housings. Cases are especially rigid to withstand severe service.

SCREWDRIVER-OPERATED ROTARY

Simplifies Circuit Testing



An aircraft equipment manufacturer needed a small, yet high current switch that could be concealed for use only during installation or routine maintenance testing of his equipment. The answer was the Hetherington Type R1043—a screwdriver-operated version of the popular R1000 Series Rotary Switch.

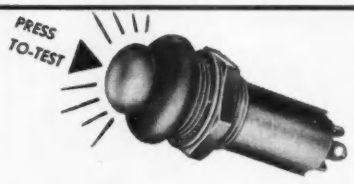
Accessible, yet readily hidden behind the chassis, the R1043 allowed easy circuit transfer from "Operate" to "Test" with far greater reliability than the space-consuming, jumper-type test fittings previously used.

Only 3/4″ in diameter, the R1043 rotary switch breaks 20 amps (resistive) at 28v dc. In spite of its size, the positive snap-action assures adequate leverage to break contact welding from overloads.

No bulletin is available on the R1043, but dimensions, ratings and contact data will gladly be sent.

For Lamp Circuits that

MUST NOT FAIL



Lamp burn-outs and circuit failures can present real hazards in critical warning light applications. To minimize the danger, the Hetherington L3000 Series allows the lamp and its circuit to be checked at any time merely by pressing on the spring-mounted plastic lens.

An anodized aluminum case seals the L3000 against dust, while a rubber "O" ring and silicone boot fully moistureproof the lens and plunger. Highly reliable AN3140 lamps used in the L3000 series add still further to the dependability.

Details on the L3000 line are in Hetherington Bulletin L-1a. Small quantities of Type L3000R (red lens, 28v) are stocked by many leading electronic parts distributors.

FAST, STOCK DELIVERIES

. . . from local Parts Distributors

In many areas you can now get immediate delivery of most popular Hetherington products . . . and at *factory prices* for less than 50 pieces.

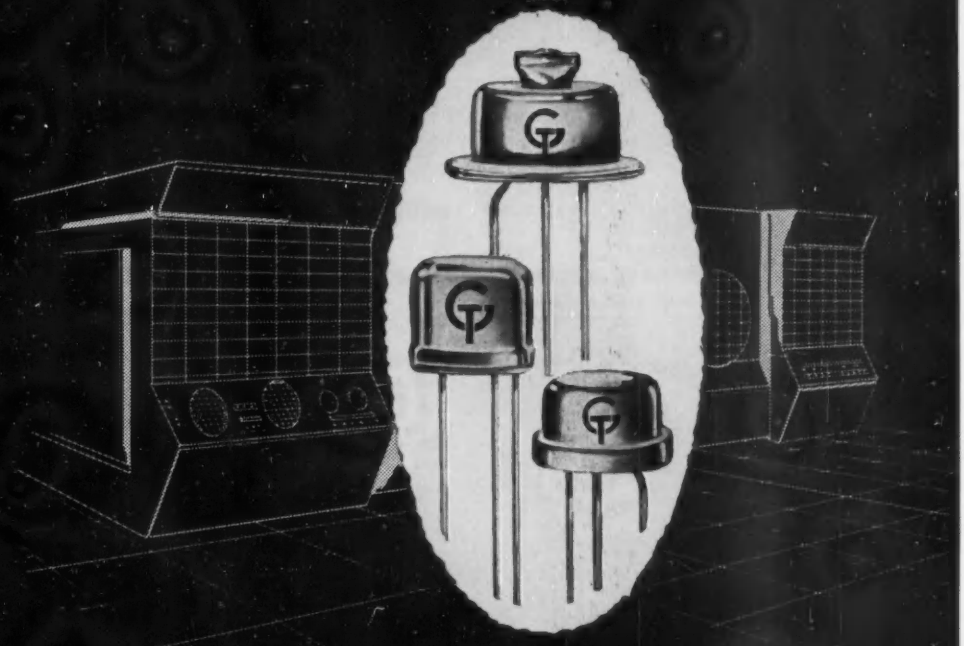
For the name of your nearest electronic parts distributor and bulletins of the Hetherington products he carries, write *directly* to: *Distributor's Div.*, Hetherington Inc., 26 Rittenhouse Place, Ardmore, Pa.

HETHERINGTON INC. DELMAR DRIVE, FOLCROFT, PA. • 139 Illinois St., El Segundo, Calif.

NOW IN LARGER FACILITIES TO SERVE YOU BETTER

VERSATILITY OF DESIGN

TRANSISTORS



G.T. computer transistors

- MINIATURIZATION
- PORTABILITY
- RELIABILITY
- EXTENDED LIFE

Simplifying and miniaturizing circuitry with GT germanium alloy type transistors, control engineers are now able to design lighter weight, portable, more reliable units than by previous methods with conventional components.

General Transistor's PNP and NPN transistors are playing a vital role in advancing the designs of control systems.

Versatility of design is now available — write today for Bulletin G-100 containing all types list and dimensional drawings.

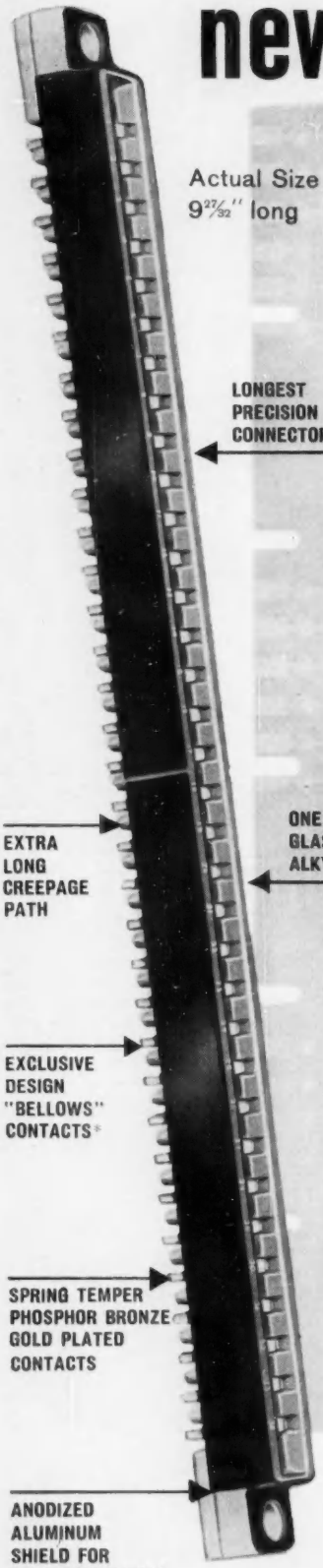
Typical Applications:

- Relay Amplifier
- Direct Current Switch
- Photoelectric readout & control
- Micro and millisecond switching
- Servo driver applications
- Control lighting
- Phase detector circuitry
- Low level modulation

GENERAL TRANSISTOR CORPORATION

91-27 138TH PLACE, JAMAICA 35, NEW YORK

new!...printed circuit Continental Connector


Actual Size
9 27/32" long
LONGEST PRECISION MOLDED CONNECTOR KNOWN
ONE PIECE GLASS REINFORCED ALKYD MOLDING
EXTRA LONG CREEPAGE PATH
EXCLUSIVE DESIGN "BELLOWS" CONTACTS*
SPRING TEMPER PHOSPHOR BRONZE GOLD PLATED CONTACTS
ANODIZED ALUMINUM SHIELD FOR HEAT DISSIPATION

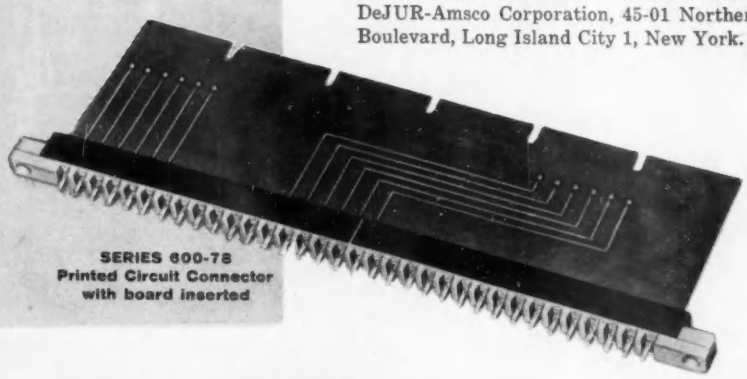
*Pat. Pending

designed for use in one of the country's largest military data processing systems

Again, Continental Connector proves its reliability and engineering know-how with this remarkable new printed circuit connector. Overall length is actually 9 27/32"... the longest, single piece precision molded connector known!

Standard molding compound is high impact reinforced glass Alkyd (other molding materials available on request). 34 contacts have .250" spacing including heavy barriers for extra protection and long creepage path. Patented "Bellows Action" contacts are conservatively rated to accept printed circuit board thickness of .054 to .072", while maintaining low contact resistance and positive spring action grip over entire printed circuit contact area. Maximum board length is 8¾". Self-alignment of "Bellows" Contacts* allows for any residual warpage of printed circuit board. An anodized aluminum shield for dissipating heat is available as an optional accessory when required (see illustration).

Our engineering staff is available for developing other unique design printed circuit connectors that may solve your special connector problems. For complete technical specifications, write to Electronic Sales Division, DeJUR-Amsco Corporation, 45-01 Northern Boulevard, Long Island City 1, New York.



SERIES 600-78
Printed Circuit Connector
with board inserted

you're always sure with **DeJUR** electronic components

progress in SIGHT SOUND SCIENCE

STEPPING SWITCHES
RELAYS and KEY SWITCHES
By Automatic Electric

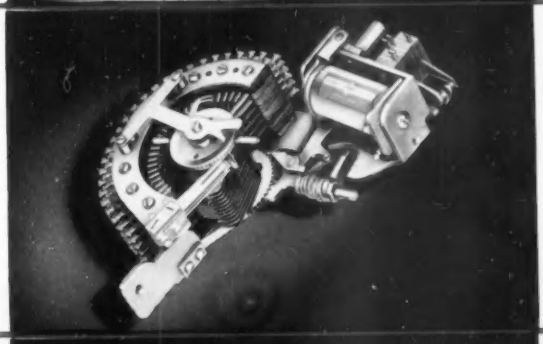
Automatic Electric, originator of the dial telephone, has been the leader in the development of "telephone type" control components for industrial use. The stepping switches, relays and other control equipment shown in this catalog are essentially the same as those used in Automatic Electric telephone equipment. Experience has proved them to be most reliable and long-lived, requiring only a minimum of service and attention.

STEPPING SWITCHES TO MEET EVERY REQUIREMENT

Fast Stepping, Smooth Running, Positive Stopping

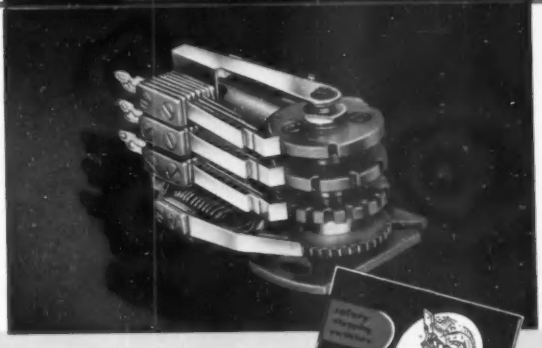
FOR COMPLICATED SPACE AND WEIGHT PROBLEMS Here's a small switch ($4\frac{1}{2}$x$2\frac{11}{16}$x$\frac{37}{64}$") with large capacity. By proper arrangement, this sturdy switch can provide 10-, 20-, or 30-point operation. One-coil design elminates the needless cost of a separate release coil. Runs efficiently at 80 steps per second (self-cycling speed). Dependable, Type 44 rarely needs adjustment in the field. This sturdy switch averages a life of 200 million steps, self-interrupted. For any d-c voltage up to 110; or for 115 volts, 60 cycles a-c, with rectifier. This switch is available with bank contact terminals to fit Aircraft-Marine Products (AMP) Series 78 "Taper Tabs."

SPECIFY TYPE 44



FOR LARGE CAPACITY REQUIREMENTS Available with 2 to 12 twenty-five point, or up to 8 fifty point bank levels. Can be used with wipers arranged independently for 25-point operation; or in staggered pairs for 50-point operation. Operates at approximately 70 steps per second for self-cycling. Type 45 is the first large capacity switch with one-piece, single-sided open-type frame. Will average a life of 250 million steps, self-interrupted. For up to 110 volt d-c, or 115 volts, 60 cycles a-c, with rectifier. Size $4\frac{13}{64}$"x$5\frac{1}{4}$"x$6\frac{7}{8}$" (for 10 levels). This switch is available with bank contact terminals to fit Aircraft-Marine Products (AMP) Series 78 "Taper Tabs."

SPECIFY TYPE 45

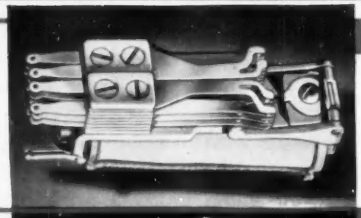


FOR CAM-SWITCHING, ALTERNATE ON-OFF, OR STEPPING Simplify engineering by using this versatile unit to combine relay and stepping switch functions. It's shock-resistant and compact. Use it for cam-switching to replace entire banks of relays and switches. You can also specify this switch to replace delicate latch-in type relays, even for applications subject to extreme shock, vibration and temperature changes. For stepping operations, stepping is high speed, accurate. Can be driven self-interrupted to produce a time cycle, or for "homing." Size: $3\frac{1}{4}$"x$2\frac{7}{16}$"x$1\frac{33}{32}$" (for three cams). Height (last dimension) for one or two cams is $1\frac{3}{16}$"; length for four to six cams is $5\frac{1}{2}$".

SPECIFY SERIES OCS

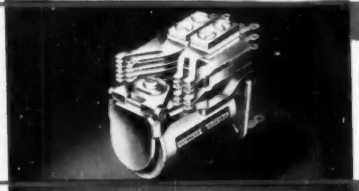
FOR COMPLETE INFORMATION on these Automatic Electric switching components, including mounting diagrams and ordering information, write for Circular 1698-PD.

A HELPFUL GUIDE TO RELAY SELECTION



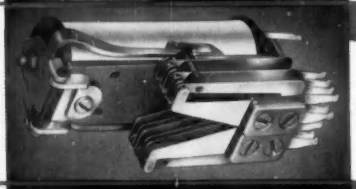
CLASS B — **FOR OUTSTANDING ENDURANCE AND DEPENDABILITY**

When extremely long service and reliable operation are demanded, this relay meets the requirements. Life often exceeds 400 million operations. Ideal for computers, fire control, pulsing or switching functions. Choose the Class B relay for the most exacting high-speed or marginal operations. For AC or DC operation.



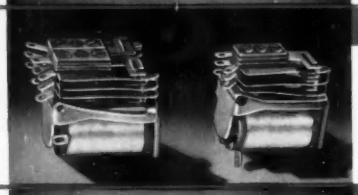
CLASS E — **A HUSKY NEW SPACE-SAVER**

Introducing a new telephone-type relay, designed for dependable long-life industrial service . . . where weight and space considerations determine size limitations. Based on the rugged Class B design, this is a universal relay, engineered for a variety of uses demanding compact size coupled with our usual high standard of reliability.



CLASS A — **WHEN FIRST COST IS IMPORTANT**

When you want relays that will hold down costs, yet provide dependable operation and long-life, specify the Automatic Electric Class A relay. This is the original "telephone-type" relay. A wide variety of coils, contacts, contact spring arrangements and mounting facilities makes this truly the "all-purpose" relay.

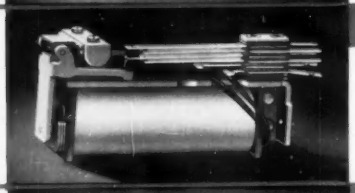


CLASS S — **FOR EXACTING MINIATURE APPLICATIONS**

Specify this relay for aircraft use, where a small, light relay is required, resistant to shock and vibration. Will meet many standard 10G vibration tests. Can be relied upon for fast pulse response because of its small mass and slight self-inductance. Voltages shown are nominal. Series SQPC available for printed circuits.

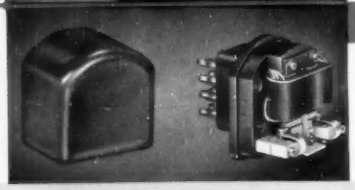
CLASS Z — **FOR MAXIMUM TIMING WITH REDUCED SIZE**

Similar to Class A relay, but smaller and does not provide the same sensitivity and range of time delay characteristics or the exceptionally large number of contact springs. Choose Class Z relays where a small, light relay is needed but long life or time delay is of greater importance than extremely small size.



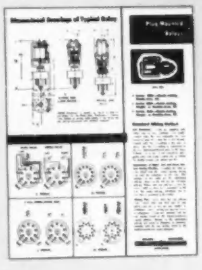
A.C. CURRENT — **FOR LOW POWER CONSUMPTION ON A. C.**

Choose this relay where the number of relays required doesn't justify a rectifier, where operate and release time delays are not a factor and where low power consumption is a must. When operate and release timing is required, an inexpensive rectifier can be supplied for use with any d-c relay shown on this page.



POLARIZED — **WHEN SENSITIVITY TO MAGNITUDE AND DIRECTION OF CURRENT ARE REQUIRED**

Series PHD and PLD are available for either "2-position" or "3-position" operation. Series PTW provides only "2-position" operation. "2-position" relays "stick" operated until current is reversed; "3-position" operation provides a neutral position for the armature when no current is flowing.



FOR DIMENSIONAL DRAWINGS, standard plug wiring diagrams and standard method of contact spring assembly, write for your copies of Circulars 1800-1804 PD.

PLUG-MOUNTING SOLVES INVENTORY, REPLACEMENT PROBLEMS

More and more design engineers are specifying plug-mounted Automatic Electric relays. They find that plug-mounting often simplifies replacement problems, minimizes inventory and practically eliminates "downtime" for routine maintenance. All relays on this page, except the Series PHD and PLD, can be plug-mounted with a choice of 8-, 9-, 12- or 20-pin plugs. Covers are available for most relays.

FOR INFORMATION on Series SQPC Relay for Printed Circuits, write for Relay Highlights No. 9 PD.

FOR INFORMATION on Series PTW Relay, write for your copy of Circular 1821 PD.

FOR MORE DETAILED INFORMATION about Automatic Electric relays and ordering information on assemblies, write for Circular 1702 PD.

SERIES	OPERATING TIME, SECONDS	RELEASE TIME, SECONDS	MAXIMUM COIL VOLTAGE	MAXIMUM NO. OF STANDARD CONTACTS	TYPE OF CONTACTS†††	WEIGHT	DIMENSIONS (MAX.) IN.
BQA	0.002-0.030	0.005-0.050	250 dc	24 Spgs.		8-12 oz.	4-3/32 x 2-3/16 x 1
BSO	0.040-0.120	0.025-0.350	135 dc	**24 Spgs.		8-14 oz.	4-3/32 x 2-3/16 x 1
BSR	0.004-0.035	0.035-0.600	135 dc	*6 Spgs.	Code 0—18 ga.	8-14 oz.	4-3/32 x 1-7/8 x 1
BSA	0.020-0.055	0.035-0.600	250 dc	*6 Spgs.	Twin	8-14 oz.	4-3/32 x 1-7/8 x 1
BFA	0.010-0.025	0.008-0.020	230 ac	24 Spgs.		8-14 oz.	4-3/32 x 2-3/16 x 1
BMS	0.010-0.030	0.015-0.050	250 dc	***2 Form C	Snap-action	7-11 oz.	4-3/32 x 2-9/32 x 1-23/32
		**Up to 0.600 sec. release time on BSO Relay with 6 springs maximum.					
EQA	0.002-0.030	0.005-0.025	150 dc	26 Spgs.			
ESO	0.015-0.050	0.050-0.125	110 dc	26 Spgs.			
ESR	0.005-0.030	0.050-0.125	110 dc	6 Spgs.	Code 0—18 ga.	2-3 oz.	2-1/4 x 1-23/32 x 1-1/8
ESA	0.015-0.030	0.050-0.125	110 dc	6 Spgs.	Twin		
EFA	0.005-0.025	0.005-0.025	220 ac	20 Spgs.			
EMS	0.010-0.030	0.015-0.030	150 dc	2 Form C	Snap-action		
AQA	0.002-0.025	0.005-0.025	250 dc	26 Spgs.		8-12 oz.	4-3/32 x 2-3/16 x 1-7/16
ASO	0.040-0.120	0.020-0.250	135 dc	26 Spgs.		8-14 oz.	4-3/32 x 2-3/16 x 1-7/16
ASR	0.004-0.025	0.020-0.350	135 dc	*6 Spgs.		8-12 oz.	4-3/32 x 2 x 1-7/16
ASA	0.010-0.050	0.020-0.350	250 dc	*6 Spgs.	Code 4—18 ga.	8-12 oz.	4-3/32 x 2 x 1-7/16
AWS	††Up to 2	0.005-0.025	250 dc	1 Form A		7-11 oz.	4-3/32 x 2-3/4 x 1-7/16
AVR	0.002-0.025	††1 to 15	250 dc	Special		8-12 oz.	4-1/4 x 2 x 1
AMC	0.210-0.280	0.300-0.345	250 dc	2	Mercury	12-16 oz.	4-3/4 x 3-1/16 x 3
SL	0.002-0.030	0.005-0.100	†175 dc	18 Spgs.		2- 4 oz.	2-1/32 x 2 x 1
SQA	0.002-0.016	0.005-0.085	†115 dc	9 Spgs.		2 oz.	1-17/32 x 2 x 11/16
SQD	0.002-0.030	0.005-0.085	†115 dc	18 Spgs.	Code 0—20 ga. Twin	2- 3 oz.	1-17/32 x 2 x 1
SQPC	0.002-0.030	0.005-0.085	†115 dc	18 Spgs.		2- 3 oz.	1-17/32 x 2 x 1
S-Power	0.005-0.016	0.005-0.010	115 dc	1 Make	Silver-Tungsten	12 oz.	1-1/2 x 1-1/2 x 1-1/4
ZQA	0.002-0.025	0.005-0.025	135 dc	13 Spgs.		4- 6 oz.	2-1/2 x 2-3/4 x 1-1/2
ZSO	0.010-0.050	0.050-0.150	115 dc	13 Spgs.		4- 6 oz.	2-1/2 x 2-3/4 x 1-1/2
ZSR	0.003-0.010	0.050-0.200	115 dc	*6 Spgs.	Code 4—18 ga.	4- 6 oz.	2-1/2 x 2-3/4 x 1-1/2
ZSA	0.010-0.040	0.050-0.200	135 dc	*6 Spgs.		4- 6 oz.	2-1/2 x 2-3/4 x 1-1/2
ZMS	0.010-0.040	0.005-0.200	135 dc	***2 Form C	Snap-action	8-10 oz.	2-1/2 x 2-3/8 x 2-1/4
ZFA	0.010-0.025	0.008-0.020	115 ac	13 Spgs.	Code 4—18 ga.	4- 6 oz.	2-1/2 x 2-3/4 x 1-5/16
Type 18	0.002-0.025	0.005-0.025	12 or 24 dc	10 Spgs.	Code 9—18 ga.	4- 6 oz.	2-1/2 x 2-1/4 x 1-1/4
FQA	0.002-0.025	0.005-0.040	To 230 (16-66 cycles)	12 Spgs.	Code 4—18 ga.	9-13 oz.	4 x 1-15/16 x 1-1/4
BFA	0.010-0.025	0.008-0.020	To 230 (20-60 cycles)	24 Spgs.	Code 0—18 ga.	8-12 oz.	4-3/32 x 2-3/16 x 1
FMS	0.002-0.006	0.002-0.008	To 240 (16-66 cycles)	2 Form C	Snap-action	10-14 oz.	3-1/2 x 2-1/8 x 2-3/8
FMC	0.298-0.333	0.290-0.350	To 240 (16-66 cycles)	2	Merc.-Glass	14-18 oz.	4-5/8 x 2-3/4 x 2-3/4
ZFA	0.010-0.025	0.008-0.020	To 115 (20-60 cycles)	13 Spgs.	Code 4—18 ga.	4- 6 oz.	2-1 x 2-7/8 x 1-11/32
PLD	0.003-0.010	0.022-0.047	350 dc	6 each side	Code 4—18 ga.	28 oz.	4 x 3-1/4 x 2
PHD	0.006-0.027	0.065-0.075	350 dc	6 each side	Code 4—14 ga.	27-37 oz.	4-13/16 x 2-3/4 x 3
PTW	0.007 Minimum	0.0002 Approx. Travel Time		1 Form C	Tungsten Carbide or Palladium	14 oz.	2-7/8 x 2-1/4 x 3-5/16

*More contacts can be accommodated at a sacrifice of operating speed and release time delay.

††Timing value obtained in conjunction with a series ASO relay and wired circuit specified in Automatic Electric Catalog 4071.

***With one snap-action switch and one open contact assembly with 8 springs maximum.

†Higher wattage obtainable with oversize coils.

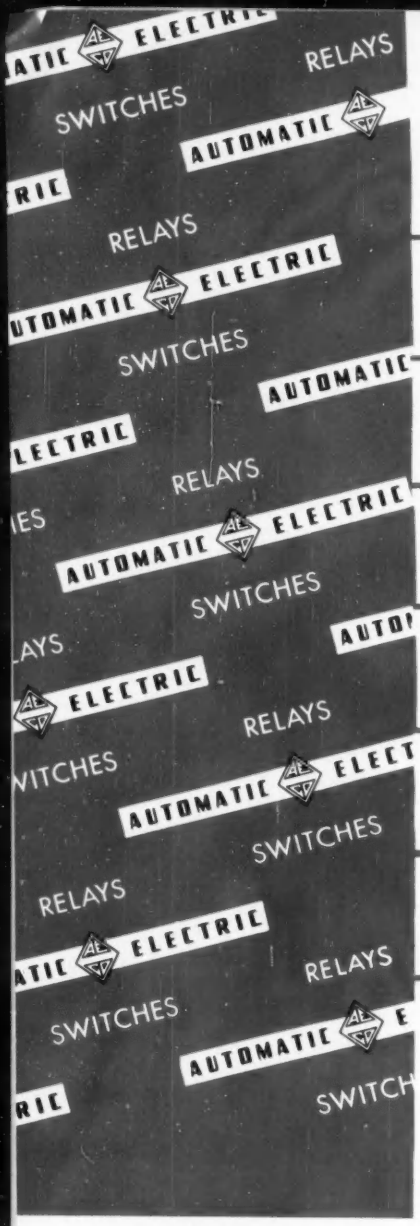
†††Most relays can be furnished with special heavy-duty high-voltage contacts.

Note: *Minimum operate time and minimum release time usually cannot both be secured on any one relay; a relay with minimum operate time may approach the maximum release time for its particular type.*

SEALED RELAYS INSURE BEST PERFORMANCE

With hermetic sealing, the high contact rating and reliability of Automatic Electric relays can be fully utilized, regardless of the surrounding atmospheric conditions. Hermetically sealed relays are safe from the dangers of human tampering, and severe conditions of dust and dirt, sand, high humidity, fungi, salt spray and reduced air pressure. To meet your requirements, many types of headers and a variety of sizes and shapes of enclosures are available.

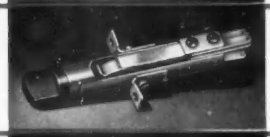
FOR DETAILED DRAWINGS of all popular Automatic Electric enclosures, write for your copy of Catalog 4083 PD.



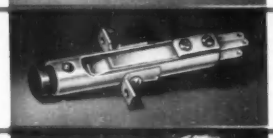
KEY SWITCHES FOR EVERY NEED.....

LEVER KEY SWITCHES are supplied for one- or two-way operation, locking or non-locking on one or both sides. Maximum 24 springs in each position. If subject to shock, specify Shok-Lok switch.

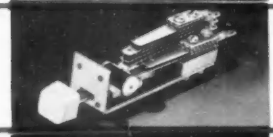
TURN KEY SWITCHES are designed for applications requiring locking-type keys. Turnbutton operates springs. Also available as non-locking. Button may be red or black.



INDIVIDUAL PUSH KEY SWITCHES require little space. May have 1 or 2 pile-ups with five springs each. Pushbutton cupped to fit fingertips. Mounts on panels up to 1" thick. Red or black buttons.



"QUICK-ACTING" PUSH KEY SWITCHES operate on a roller, providing fast, free action. Pushbutton can be engraved with a one-digit number. Mounts on panels up to ¼ inch.



COMPACT STRIPS OF PUSH KEY SWITCHES provide groups of ten or twenty switches in a very small space (11½"x1½"x4"). Can be locking or non-locking. Buttons can be red, green or black.

JACKS AND PLUGS for two- or three-conductor cords, are available for practically every need. Jacks can be sleeve-mounted or with fixed sleeves. Jack strips and multiple jacks also available.

FOR KEY SWITCH REFERENCE DATA, and a complete list of key switches and associated equipment, write for catalog 4018 PD.

FOR ADVICE ON SPECIFIC PROBLEMS . .

The specialized resources of Automatic Electric's laboratories and production facilities are at your disposal at all times. Simply call or write your regional Automatic Electric representative.

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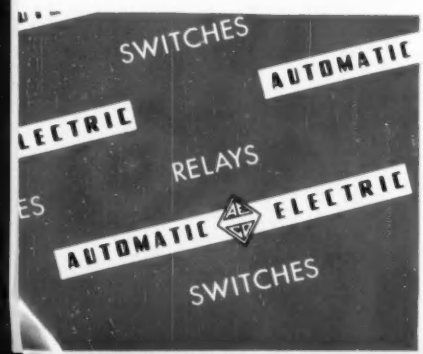

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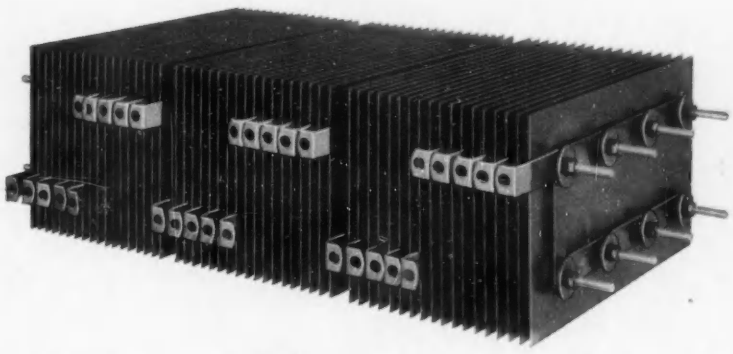
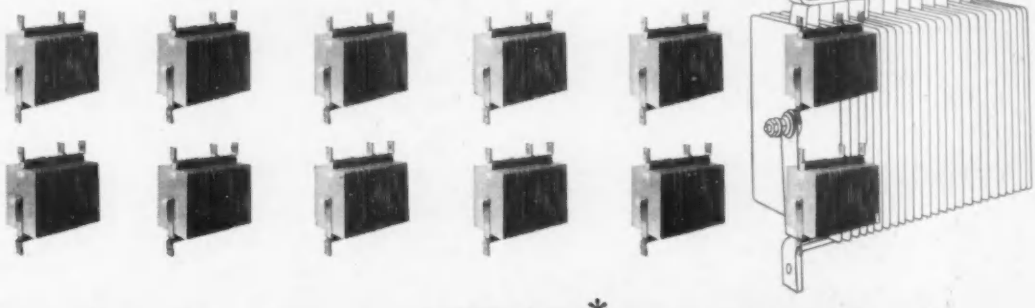
12 full size conventional stacks!





Radio Receptor HCD* Petti-Sel

**High current density*

Industrial Type Selenium Rectifiers

Produced by the improved new vacuum process developed by Siemens of West Germany and now manufactured exclusively by Radio Receptor in the U.S.

Smaller cell sizes

Lower voltage drop

No artificial barrier

Negligible aging with an estimated life of 100,000 hours!

Because the exclusive Siemens vacuum process eliminates the need of an artificial barrier layer, it is possible for Radio Receptor to offer smaller cell sizes operating at high current density, yet with lower voltage drop. In actual dimensions this means that just *one* RRco. HCD rectifier measuring 8" x 16" x 25", rated at 26V AC, 4500 amps DC, replaces *twelve* usual stacks 6" x 7¼" x 10".

RRco. Petti-Sel rectifiers do far more than save space. They reduce assembly time, require fewer connections and cost less per ampere. Their dependability has been proved for years in European circuits and the outstanding electrical characteristics are not even approached by other standard cells available today. For further information please write today to Section C-9R.

Radio and Electronic Products Since 1922

Semiconductor Division

RADIO RECEPTOR COMPANY, INC.

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Radio Receptor products for Industry and Government:
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Astounding

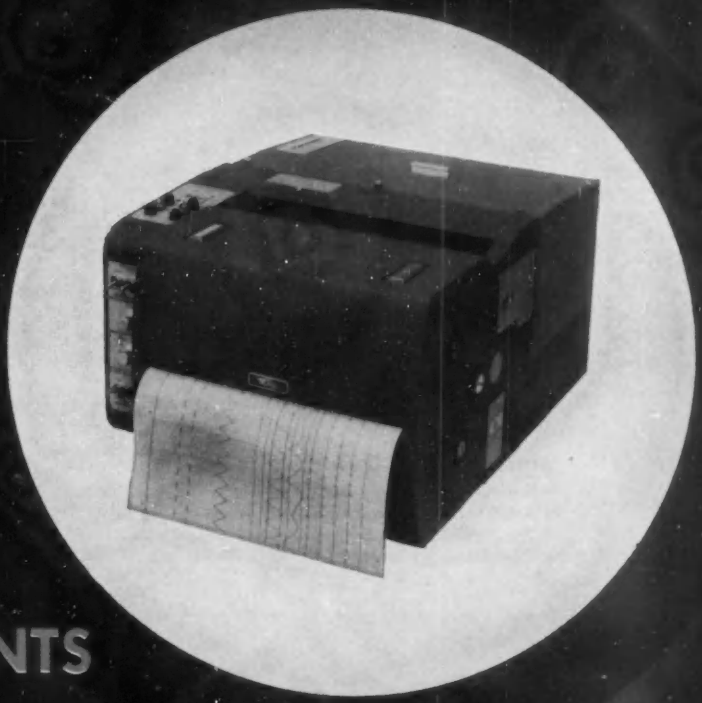
NEW
PERFORMANCE

MIDWESTERN direct/riter OSCILLOGRAPH D/R* 602

*DIRECT READOUT WITHOUT PROCESSING
SELF-DEVELOPING • DRY • NO CHEMICALS

SPECIFICATIONS:

MAXIMUM NUMBER OF CHANNELS	50 Channels
RECORD WIDTH	12 inches
MAGAZINE CAPACITY	200 feet
RECORD SPEED RANGE	0.0812 to—129.9 inches per second
FREQUENCY	dc to above 3,000 cps
WRITING SPEED	Above 30,000 inches per second
OPTICAL ARM	11 inches—
POWER REQUIREMENTS	115 Volts—60 cps
TIMING LINES	0.01 and/or 0.10 second intervals
SIZE	11 1/16" x 16 13/16" x 24 1/2"
WEIGHT	130 pounds



5 EXCLUSIVE ADVANCEMENTS

Up to 50 channels of information

Uses standard 102 Galvanometers

Provides timing lines, record numbering and many other advancements

30,000 inches per second writing speed with excellent legibility dc to above 3,000 cps

Seven inch or twelve inch records

Wire for Brochure: **FAX-FCB TULSA**

MIDWESTERN

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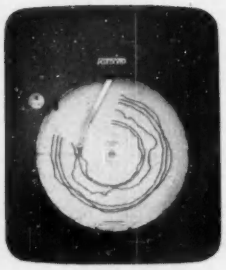
P. O. BOX 7186 TULSA, OKLAHOMA

GET THE BEST SOLUTION TO ANY TEMPERATURE

from –450°F

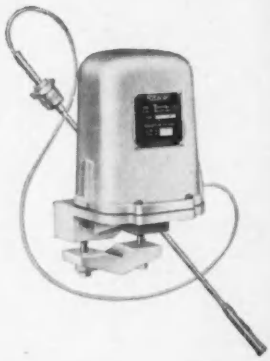


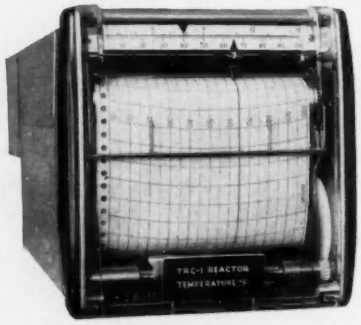
Dynalog Electronic Instruments

Complete line of indicators, recorders, and controllers employing the advanced Dynalog measuring system in which a friction-free air capacitor replaces conventional slidewire — provides continuous, stepless balancing action. Dynalog Instruments provide up to six records on a single round chart. For use with resistance or voltage type primary elements — pneumatic or electric control action.

Multi-Record Dynalog

- 6 color-coded temperature records on one round chart.
- Each record line a distinctive, non-smudging color.
- No slidewire — no batteries — no standardizing.
- Thermocouple or resistance bulb types.





Consotrol® Recording Control Station

One of the complete Consotrol line of compact panel indicators, recorders, and controllers. This advanced control station features full 4" chart and scales, six-months' ink supply, bumpless auto.-man. transfers. The M/58 Consotrol Controller, shown here integrally mounted, provides:

- All four control actions, with two reset ranges, easily adjustable to widest variations in operating conditions.
- Easy lever-setting proportional band, calibrated to 500%.
- High sensitivity and precision due to unique "floating disc" balancing action — even at widest settings of proportional band.
- Interchangeable "plug-in" components.
- Continuously variable reset resistance gives 500:1 rangeability.

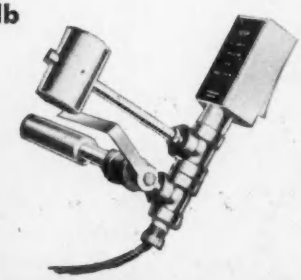
PRIMARY ELEMENTS

A complete selection of primary elements, including filled thermal systems, resistance bulbs, and thermocouples. Besides these standard types, special elements and accessories are available to meet the requirements of practically any industrial temperature problem.

Dynatherm Resistance Bulb

For use with Dynalog Electronic Instruments.

- Superior measurement performance for temperature up to 600°F.
- Fastest response due to positive metal-to-metal end contact with standard wells or sockets.
- Highest sustained accuracy. Permits use of extra-narrow scales — ideal for precise temperature difference measurements.



Roll Surface Temperature Element

- Continuous, automatic measurement or control of roll surface temperatures up to 450°F.
- Extra-rugged construction — with a "feather" touch. Won't mark or score the roll.
- Eliminates friction, radiation, and convection errors.
- Simplest, most accurate way to measure roll surface temperatures.

PROBLEM | with Foxboro Instrumentation to +2800°F

Whenever you have a temperature problem in the −450°F to +2800°F range, you can depend on Foxboro Instrumentation for the best solution. Foxboro's outstanding combination of truly advanced instruments and unequaled experience in applying them, has successfully solved temperature problems as widely different as helium liquefaction and jet engine testing.

Foxboro offers a wide variety of primary elements, transmission devices, indicators, recorders, and controllers. Whether a single instrument or a combination is required — filled-system, electronic, or electric — you can be sure of fitting the process *exactly*. Unique Foxboro developments, such as Dynalog* Electronic Instruments, Dynatherm** Resistance Bulbs, and the 12A Temperature Transmitter, continually maintain control standards in step with every advance of modern processing.

A few of the instruments which typify Foxboro's better-engineering are shown on these pages. Chart below shows complete temperature ranges covered by Foxboro measuring systems. Write for complete details. **The Foxboro Company, 369 Norfolk St., Foxboro, Mass.**

Type 12A Temperature Pneumatic Transmitter

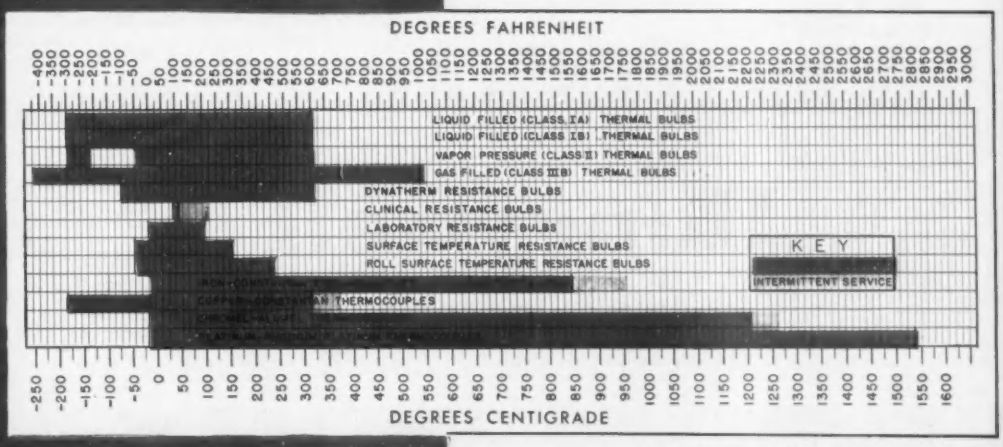
- Simple way to measure remote temperatures in the −100°F to +1000°F range. Operating spans of 50°, 100°, 200°, and 400°F.
- Compensated for ambient temperatures and pressures.
- Compact, easily installed. Uses regular 1/4" O.D. tubing transmission lines — no troublesome conduits, no costly capillary tubing.
- Suitable for any hazardous, corrosive, or outdoor location.

Filled Thermal System Instruments

- Give highly accurate, "lifetime" service within range of −450F to +1000F.
- Most economical of all temperature measuring systems. Require no maintenance under normal operating conditions.
- Available as liquid filled, vapor pressure, or gas filled systems.
- Complete line of indicators, recorders, and controllers in rectangular or circular case models.

FOXBORO
Reg. U.S. Pat. Off.
TEMPERATURE
measurement and control

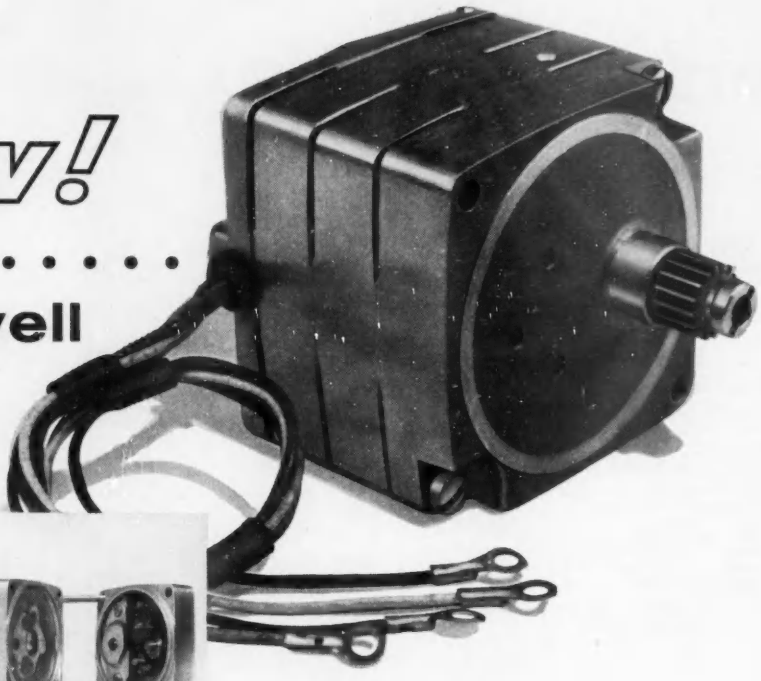
Locate your problem temperature in this table

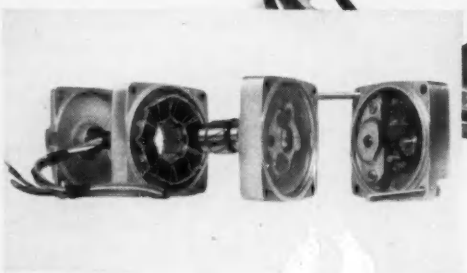


*Reg. U.S. Pat. Off. **Trademark

New!

Honeywell Motors





for chart drives, servos, balancing circuits, remote positioners

Now from Honeywell come these newly-designed synchronous and two-phase motors of highest quality. New, sectioned die cast housing . . . new wicking to prevent oil leakage . . . ball bearings to reduce friction . . . printed circuits . . . are some of their many maintenance-saving features. What's more, you can replace any part in two minutes, usually without disconnecting the leads from your installation.

Order these motors in small quantities for prototype development, or by the thousands for production runs. Models charted at right are available for fast, dependable delivery.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, Wayne and Windrim Aves., Philadelphia 44, Pa.

TWO-PHASE INDUCTION

Nominal No-Load RPM*	Gear Ratio	Intermittent Rated Load (oz.-in.)	Max. Starting Torque (oz.-in.)	Power (watts)† Loaded	Current (amps.) Loaded	Temp. Rise Deg. F
330	44:1	4	10	7.6	.11	70
148	10:1	5	20	7.0	.11	70
44	30:1	15	50	7.6	.11	70
22	60:1	30	120	7.6	.11	70

†6.0 watts in field winding, balance in amplifier winding.

SYNCHRONOUS

RPM*	Gear Ratio	Pull-In Torque, Min. (oz.-in.)	Continuous Torque (oz.-in.)	Power (watts) Loaded	Current (amps.) Loaded	Temp. Rise Deg. F
180	10:1	12	12	19	.21	100
180	10:1	3.5	4	13	.11	65
90	20:1	14	12	11	.095	55
60	30:1	13.5	12	13	.11	65
30	60:1	27.5	12	13	.11	65

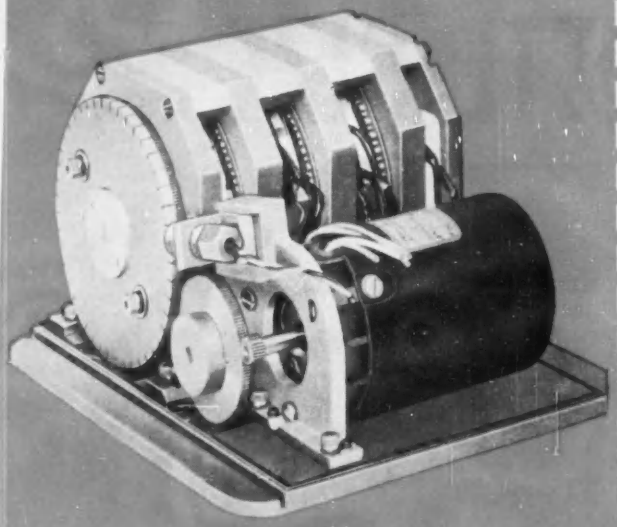
*1/6 less at 50 cycles. Some speeds availabe at 25 cycles.

Weight: 29 oz. **Write for Specification S900-3.**

Honeywell

First in Controls

DESIGN ACHIEVEMENTS WITH **SUPRAMICA*** ceramoplastics



RELIABILITY DOES NOT COST EXTRA

MYCALEX* TM commutation switches set new standards of reliability for aircraft and missile telementry

$25,000 a minute is costly time — but that is the estimated value of the final "count-down" for a major missile test.

Telemetered information will record the vital history of the flight and point the way to new developments and advancements. To achieve complete control, absolute dependability and long life, precision equipment is essential, both during flight and during the "count-down" when a complete check-out is demanded. Cleaning and adjusting commutators during the final hours or minutes of "count-down" is expensive — and wasteful.

MYCALEX* TM commutation switches with precision molded commutator plates of SUPRAMICA 555 ceramoplastic introduce new standards of reliability to this important operation. Hundreds of hours of **completely unserviced life** with dependable, low-noise-level signals is definitely attainable. Customer evaluation tests have shown satisfactory operation of MYCALEX TM switches for over 1000 hours at 1200 RPM with only brush cleaning and routine maintenance.

These exceptional performance standards are possible because of painstaking precision assembly and testing, and the use of SUPRAMICA ceramoplastic commutator plates, which have total, permanent dimensional stability and will withstand temperatures as high as 500 degrees C. without distortion or contact loosening.

MYCALEX TM commutation switches and SUPRAMICA ceramoplastics are making significant contributions to the reliability and durability of electronic equipment for military and civilian applications.

Write for detailed information.

*MYCALEX and SUPRAMICA are registered trade-marks of Mycalex Corporation of America. 555 is a trade-mark of Mycalex Corporation of America.

MYCALEX
CORPORATION OF AMERICA

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EXECUTIVE OFFICES:
30 ROCKEFELLER PLAZA
NEW YORK 20, NEW YORK

GENERAL OFFICES AND PLANT:
CLIFTON, NEW JERSEY

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WASHINGTON – MIAMI

WORLD'S LARGEST MANUFACTURER OF GLASS-BONDED MICA AND CERAMOPLASTIC PRODUCTS

COMPUTER THERMOSTATS NOW CIGARETTE SIZE

Some Fenwal Units Smaller Still Take Little More Room Than Sugar Lump

ASHLAND, MASS. — If you want to control temperatures in tight spots, you should see Fenwal. Fenwal has cut the size of thermostats way down.

You can fit one of their Midget THERMOSWITCH units anywhere a cigarette will fit. And, if you're working with even less space, one of their Miniature THERMOSWITCH units is what you're looking for. The Miniatures are little bigger than a lump of sugar, and some are even smaller.

The Midgets and Miniatures use the same unique principle used in Fenwal's bigger THERMOSWITCH controls. They use it with the same high degree of success.

The principle of all Differential Expansion THERMOSWITCH units, large or small, is this: a single metal shell expands or contracts with temperature changes, making or breaking totally enclosed electrical contacts.

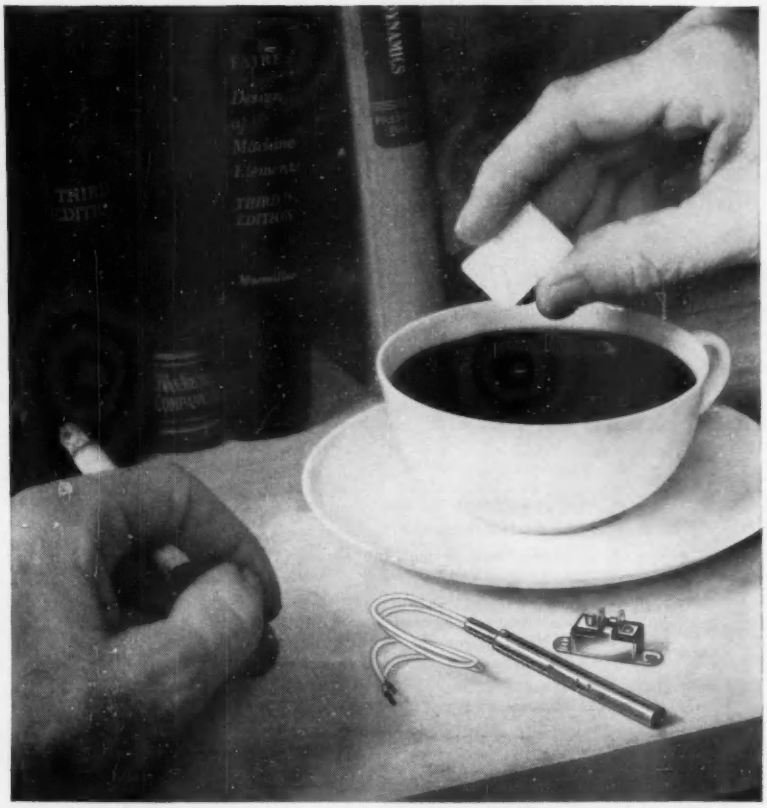
The smallness of the Midget and Miniature units does not deprive them of any of the performance characteristics that have made larger THERMOSWITCH units famous. They have THERMOSWITCH ruggedness, THERMOSWITCH accuracy, and reasonable THERMOSWITCH prices.

Temperature range of the Midget series: −50°F to 500°F. Range of the still smaller Miniature series: −20°F to 275°F.

Midgets and Miniatures, all in stainless steel, come in a variety of mountings. Hermetic sealing is also available.

These Fenwal THERMOSWITCH units are precision-engineered to give optimum temperature control with minimum-sized devices. They remain accurate under the most severe operating conditions.

You should have details on this advance in temperature control at your fingertips. Write for information to **Fenwal Incorporated, 599 Pleasant Street, Ashland, Massachusetts.**

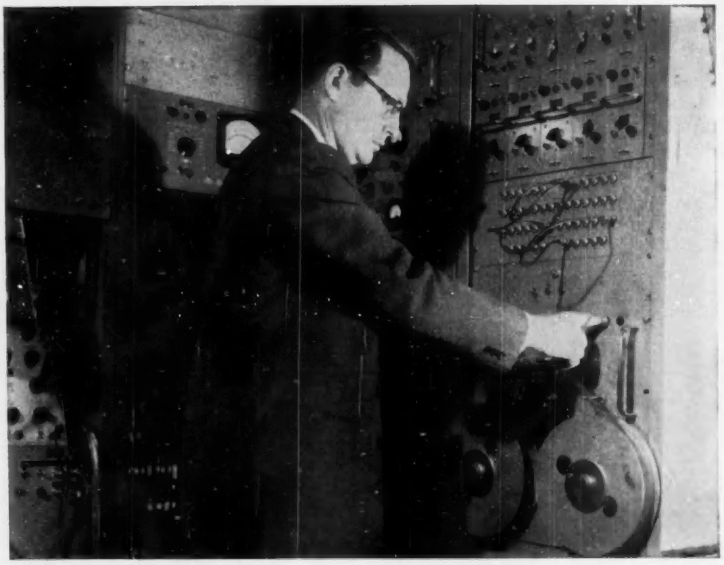


THERMOSTATS FOR TIGHT SPOTS — A Fenwal Midget THERMOSWITCH® unit and a Fenwal Miniature THERMOSWITCH unit — two good answers to the question, "How can you install an accurate, reliable thermostat where there's almost no room?" Actual sizes of these particular models — ¼" x 2 25/32" for the Midget; 1" x ½" for the Miniature.

Fenwal

CONTROLS TEMPERATURE ...PRECISELY

CONTROL TRANSFORMER
LINEAR TRANSFORMER
Newest!
MOTOR
DIFFERENTIAL
cppc
OFFERS A
COMPLETE LINE
OF SIZE 8
TRANSMITTER
ROTARY COMPONENTS
MOTOR GENERATOR
Newest!
including
SYNCHROS (all types)
RESOLVERS
D.C. MOTOR
LINEAR TRANSFORMER
MOTOR GENERATOR
RECEIVER
RESOLVER
Clifton Precision began delivering Size 8 synchros from the production line more than a year and a half ago. Since then production has mounted steadily, and we are now in a position to serve more and more customers with these 7 minute accuracy units.
We have also recently produced a linear transformer and motor generator in the size 8 series.
For information, write or telephone: Sales Dept. 9014 West Chester Pike, Upper Darby, Pa. SUnset 9-7521, or our representatives.
cppc
CLIFTON PRECISION PRODUCTS CO., INC.
CLIFTON HEIGHTS
PENNSYLVANIA

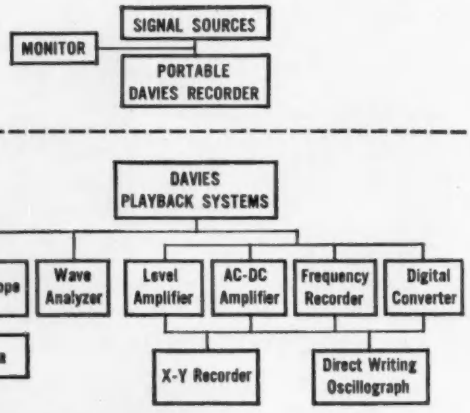


General Electric Company's Charles A. Woodcock begins analysis of aircraft gas turbine operating dynamics by pressing "Start" button on one of two Davies Division magnetic tape systems at the Flight Propulsion Laboratory Dept. Data Reduction Center, Evendale, Ohio.

how G.E. data center analyzes dynamic jet engine operation

G.E. wants to know a lot of things about an aircraft gas turbine before it leaves the ground. Not just thrust, pressure, temperature . . . but vibration and stress characteristics too. While suitable equipment has long been available for recording and measuring the "static" operating characteristics, only the last five years have seen reliable techniques introduced for measuring, recording, and reducing significant information from dynamic signal sources.

A pioneer in the application of these techniques, General Electric's own dynamic data handling installation at the Flight Propulsion Laboratory Department, Aircraft Gas Turbine Division, Evendale, stands as one of the most complete in the country. Originally conceived by the Laboratory, the facility has contributed substantially to the outstanding progress of aircraft gas turbine design at G.E. Data recorded at the test site can be played back through two tape systems at the Laboratory into electronic data analysis equipment and analog and digital displays for a fast, detailed picture of gas turbine performance.



The substantial part played by magnetic tape in the system reflects its growing importance as the common denominator of dynamic data handling. Dynamic range and frequency range are several times greater than characterize other recording media, and the data is stored "live". The original electrical transducer signal can be accurately re-created whenever desired for observation and processing.

Five portable magnetic tape data recording systems are used by G.E. to collect data at the engine test cells. Signals ranging in frequency from DC to 30 kc, are recorded by Direct or FM carrier techniques. Wide 1¾" tape carries 28 tracks of data, plus reference frequencies, timing signals, and voice, as desired. Monitoring oscilloscopes permit visual observation of the recorded signals. It is interesting to note that the five *portable* recording systems were originally designed by the Davies Laboratories Division for the limited space and severe environments of aircraft flight testing. The strength built into them has proved invaluable to G.E. despite the fact that they have never been operated in the air.

With the completion of a test, the reel of tape is transferred to the data reduction center. Two complete Davies Division laboratory record-reproduce systems permit utmost flexibility in feeding tracks of data serially or simultaneously into reduction and display equipment. Oscilloscopes permit a quick look at results through rapid visual inspection; wave analyzers provide a record of frequency components; level recorders measure amplitude; direct-writing recorders and oscilloscope cameras permit a complete record of wave shapes and phase relationships.

Davies Division magnetic tape data recording installations as large and complex as this one at General Electric Company can rarely be outfitted with standard package equipment. But for the smaller installations, recently announced Davies Universal Magnetic Tape Systems are an ideal choice. You can get a good background in magnetic tape data recording techniques in general by requesting our Bulletin 1001. Universal Systems are covered in Bulletin 2701. Minneapolis-Honeywell Regulator Company, Davies Laboratories Division, 10721 Hanna Street, Beltsville, Maryland. Or call WEbster 5-2700.

MINNEAPOLIS **Honeywell**

DAVIES LABORATORIES DIVISION

What's your tubing problem?

corrosion?
damage?
installation?
fire? cost?

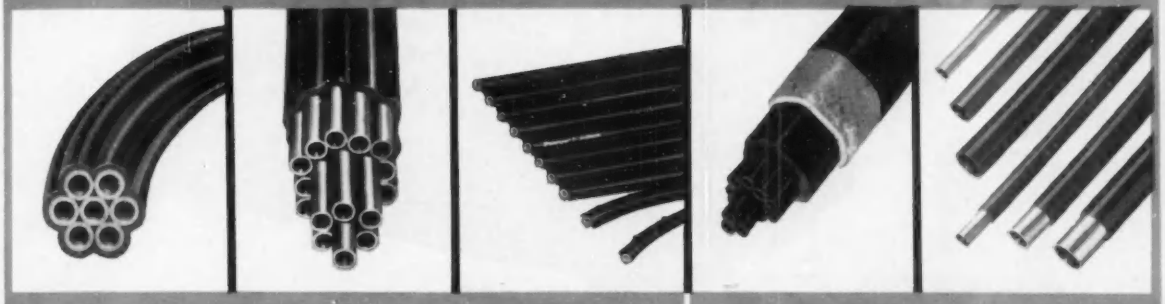
Wherever instrument tubing is used—be it refinery, natural gasoline plant, chemical, nuclear or food processing—Dekoron Tubing Products can help whip your ultimate twin problems of *maintenance-replacement expense and installation costs.*

Why?

First, because Dekoron Tubing products resist chemical attack and corrosion caused by moisture and industrial atmospheres. That means that once installed, Dekoron products are in to stay. You're not faced by perennial replacement and maintenance costs.

Second, the big savings in cost are yours in installation when you specify multiple-line Dekoron products—you install many instrument lines at once.

So if you have an instrument tubing problem of *any sort*, we probably have the answer *in stock*. If not, we can design and make it for you.



POLY-COR
From 2 up to 37 plastic tubes in plastic armor.

METL-COR
From 2 up to 19 copper or aluminum tubes in plastic armor.

RIBBON
M-Ribbon (metal) and P-Ribbon (plastic). 10 tubes in plastic sheath.

PROTECTO-PAC
Fire and impact resistant. Plastic tubes covered with plastic-asbestos-plastic armor.

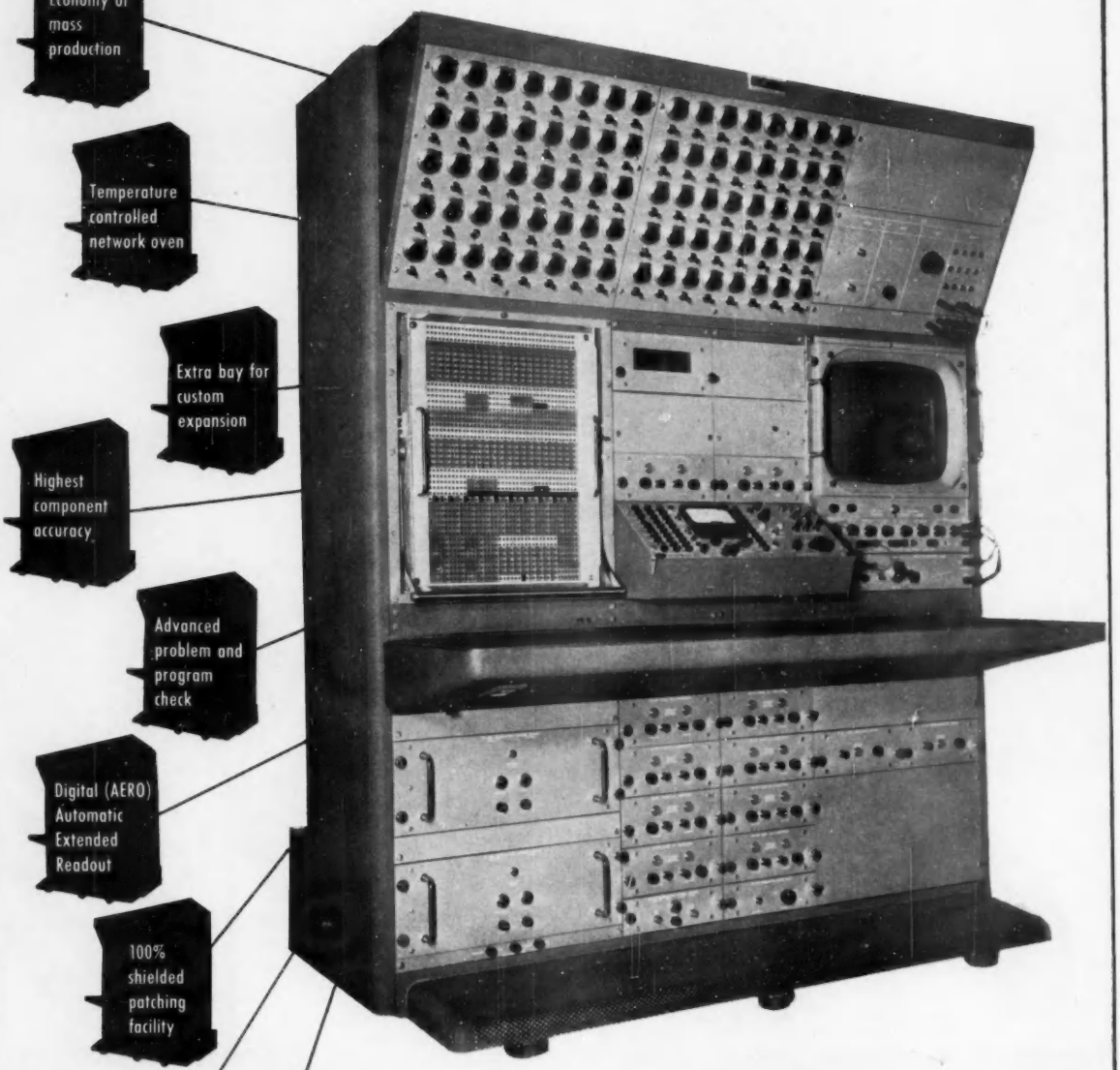
SINGLE-LINE
Single steel, copper or aluminum tubes in plastic armor, or all-plastic tubing.

Dekoron® products
QUALITY • RESEARCH • SERVICE

SAMUEL MOORE & CO.
Dekoron Products Division
MANTUA, OHIO

SEE DEKORON TUBING PRODUCTS ON DISPLAY AT THE CONVENTION **BOOTH 1017**

AA-4055



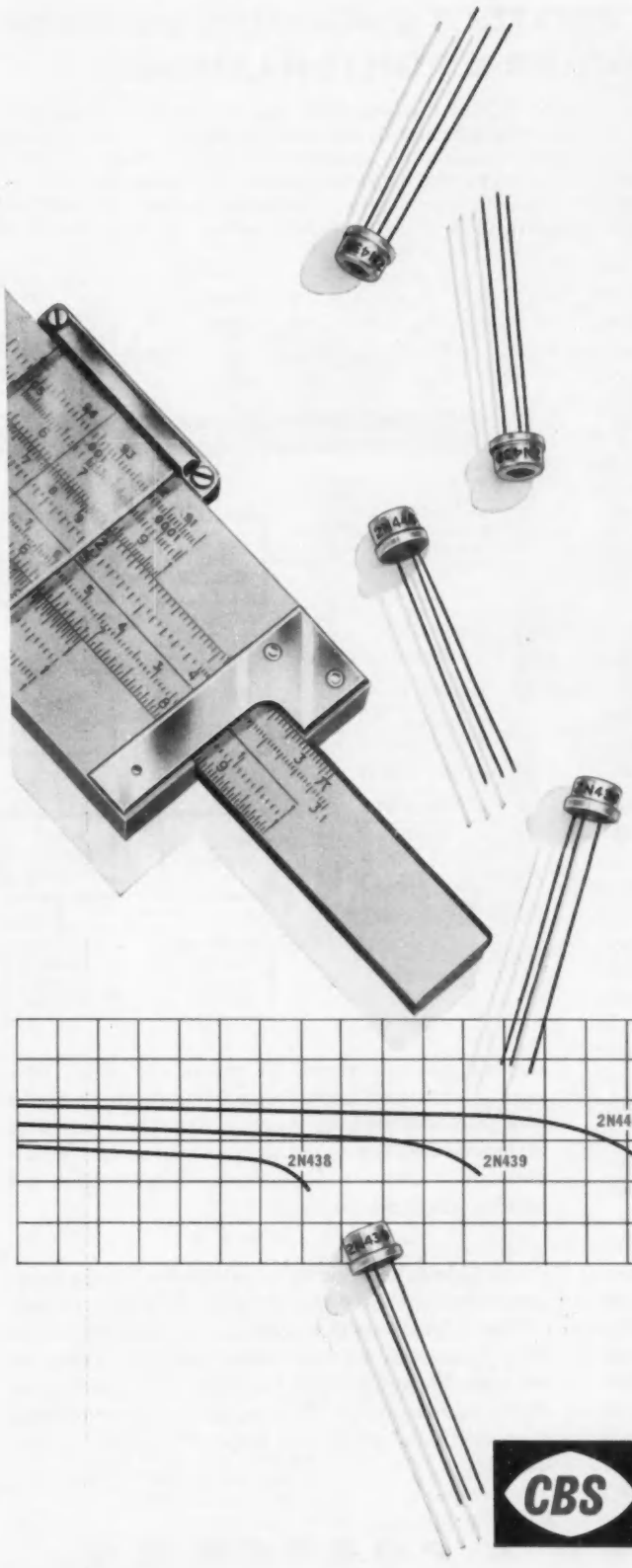
For details on this PACE Analog Computer Group 131R and on time rental at EAI's Computation Centers—serving eastern industry in Princeton, New Jersey—serving Western industry in Los Angeles, California—serving European industry at Brussels, Belgium, write Electronic Associates, Inc., Dept. CE-9, Long Branch, New Jersey.

ELECTRONIC ASSOCIATES Incorporated

EAI SETS THE PACE

P PRECISION A ANALOG C COMPUTING E EQUIPMENT ®

LONG BRANCH • NEW JERSEY



For high-speed switching

CBS HIGH-FREQUENCY TRANSISTORS

2N438
2N439
2N440

These transistors are designed for high-speed switching, control, analog and digital computer applications. All three are available in symmetrical versions, and they feature:

1. *JETEC Case* . . . employs a standard metal case (with .200 inch pin spacing) welded to achieve reliability never before approached with NPN transistors.
2. *Alloy-Junction* . . . for greater uniformity, higher voltage and current, flatter gain, and lower saturation resistance.

Note the many desirable features. Write for Bulletin E-268 giving complete data and helpful application notes.

CHECK THESE FEATURES

1.	High frequency response:	
	2N438	2.5 to 5 mc.
	2N439	5 to 10 mc.
	2N440	10 to 20 mc.
2.	High operating voltage	up to 30 volts.
3.	High switching speed	below 0.2 μsec.
4.	High current amp. factor	up to 100.
5.	High dissipation rating	up to 100 mw.
6.	Low leakage current	3 μamps av.
7.	Low base resistance	150 ohms av.
8.	Low collector capacitance	10 μμf.

Reliable products
through Advanced-Engineering.

CBS semiconductors

CBS-HYTRON
Semiconductor Operations, Lowell, Mass.
A DIVISION OF COLUMBIA BROADCASTING SYSTEM, INC.

FLEXIBILITY PROTECTS YOUR INVESTMENT IN A FISCHER & PORTER LOGGER

The modular construction of Fischer & Porter's Series 1200 may well be the best insurance available today against early logger obsolescence. In the event of process change or expansion, you can easily substitute or add subsections, preserving the custom character of the logger at minimum expense. And this logger thrives under the same maintenance procedures that keep ordinary process instrumentation on the line. Thoroughly proved in actual field operation, Fischer & Porter Loggers have already brought automatic data logging to more than thirty plants.

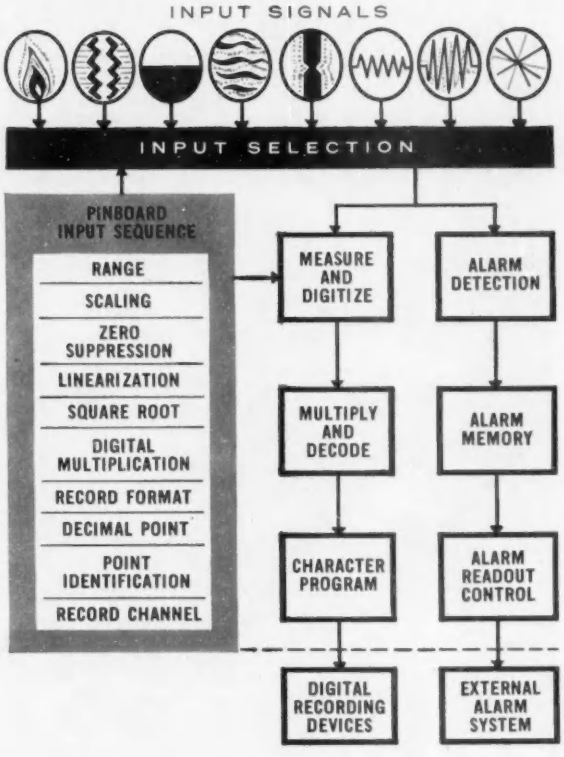
Inputs: Accepts any combination of up to 200 or 2000 inputs depending upon the scanning method used, making conversions to DC voltages, performing zero offset, scaling, and characterizing non-linear inputs. Inputs are DC, AC, variable frequency, or pneumatic.

Scanning: Two scanning systems are available. One utilizes individual point relays, with individual alarm limit set points and ranging adjustments, to provide maximum reliability and flexibility. The other provides ten times the input capacity by means of ten point stepping switches. All points on a switch share the same alarm limits, the same programs.

Analog-To-Digital Conversion: Utilizing proved electronic or, if desired, electromechanical techniques to secure speed, accuracy, and reliability, Fischer & Porter analog to digital converters provide contact closures for operating output equipment directly from shaft rotation or voltage signals.

Programming: Just as modular construction throughout the Series 1200 assures long range versatility, pinboard programming provides day to day flexibility. Programs and format are easily set up, easily modified to meet changing process requirements. Pin location establishes sequence in which inputs will be measured and read out . . . and permits readout of any input any number of times per logging cycle. It also selects any input for visual readout on a digital in-line display. In addition, the pinboard permits control of all other scan-log functions by the insertion of pins into several modular subsections which designate for each reading the type of measurement . . . digital multiplication factor . . . range . . . zero suppression . . . point identification . . . digital record format . . . decimal point location and one or more digital recording devices.

Alarm Detection: Between logging cycles, which occur on demand or at pre-set intervals, inputs are continuously scanned and compared against limit set points. Whenever an off-normal condition is detected, a complete logging cycle is initiated. All off-normal conditions are printed in red. If desired, an external audible alarm is simultaneously energized. After this logging cycle is completed, alarm scanning is resumed until another variable goes off-normal, or until a previously



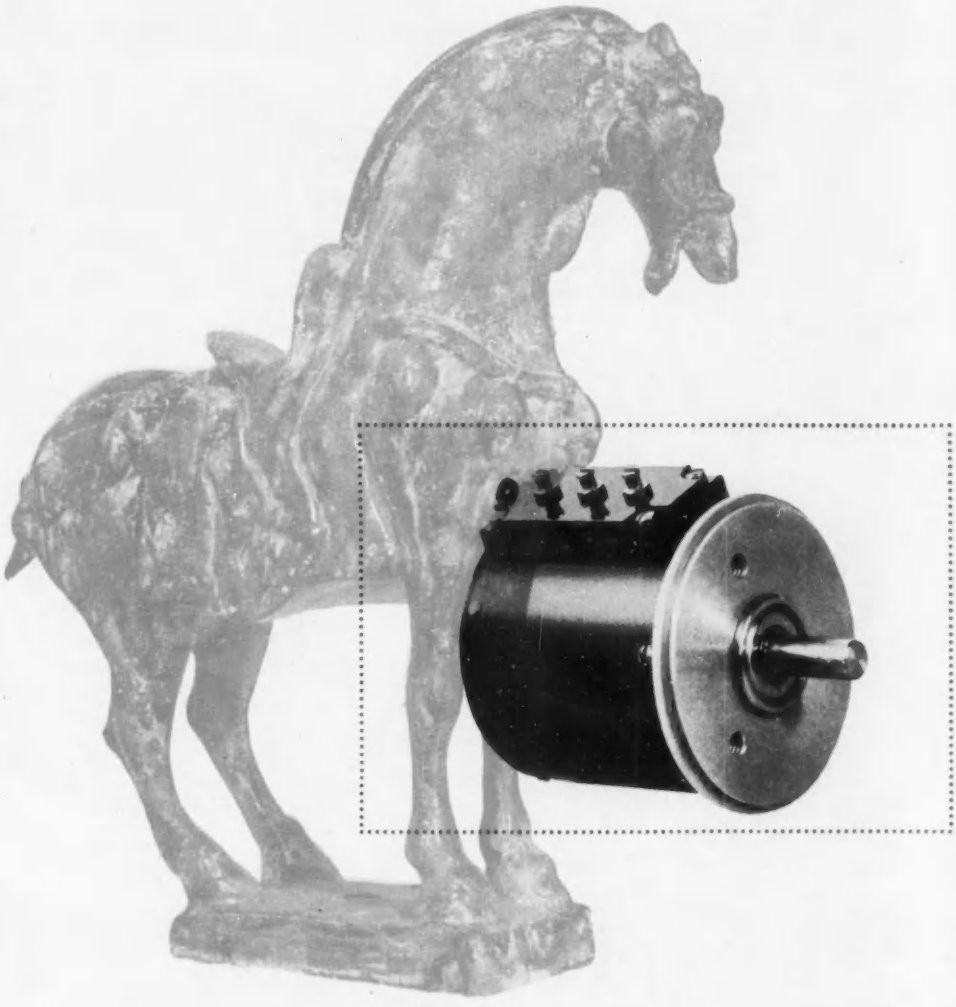
alarmed variable returns to normal, at which time logging is initiated again. Series 1200 Loggers equipped with point identification programming subsections may be programmed to record only the off-normal inputs when an off-normal condition arises, logging them on a separate alarm typewriter.

* * * *

If you'd like to hear more about the Series 1200 Scanner-Logger and how its versatility and flexibility can make reliable automatic data logging a reality in your process, get in touch with the F & P Sales Engineer nearest you. Or, write Fischer & Porter Company, 797 County Line Road, Hatboro, Pa. In Canada, write Fischer & Porter (Canada) Ltd., 2700 Jane Street, Toronto, Ontario, Canada.

FISCHER & PORTER CO.

Complete Process Instrumentation



Ceramic thoroughbred . . . with 0.01% linearity

POTENTIOMETER SPECIFICATIONS

.05% to .01% independent linearity
1K to 100K standard resistances
.02% to .005% resolution depending upon resistance value
3600° +1°/−0° electrical angle
5 watts power dissipation at 40° C
Taps are welded and can be supplied in any location on special request
90° nominal overtravel
1.0 oz. in. starting torque
0.75 oz. in. running torque
500 oz. in. static stop torque
Servo mounting standard

In our new potentiometer we took our cue from a fundamental fact: the simpler the better. We eliminated a number of individually machined and mounted parts and returned to a material that has handsomely served some of the world's oldest civilizations. Namely, ceramic.

The MD 20 potentiometer can function consistently at 0.01% linearity under severe conditions. The ceramic core is dimensionally stable. Its coefficient of thermal expansion closely matches the resistance element mandrel for high temperature operation. A simple, one-piece aluminum hub provides an accuracy reference that is extremely rugged.

Applications of the MD 20 are more varied than those of other potentiometers available today. We invite you to see it and discover how it may provide the breakthrough you've been looking for.

LITTON INDUSTRIES Components Division

EASTERN PLANT AND SALES OFFICE: DEPT. A, MOUNT VERNON, N. Y. DIVISION HEADQUARTERS: 5873 RODEO ROAD, LOS ANGELES, CALIFORNIA.

Cool That Cabinet—Save Sensitive Components

GENERAL FEATURES

- Pressurizes Cabinet With Filtered Air
- Rubber Isolated Motors For Quieter Operation
- Widely Accepted for Use In Military Equipment
- Maximum Air Delivery For Efficient Filter Action

PHOTO COURTESY APPLIED SCIENCE CORP. OF PRINCETON

ADDITIONAL FEATURES FOR BLOWER TYPE UNITS

- Provide Better Air Delivery Against Pressure
- Provide Quieter Operation Against Pressure
- Higher Air Velocity For Faster Cooling
- Air Flow Maintained With Dirty Filter
- Duct Connections Can Be Made If Desired

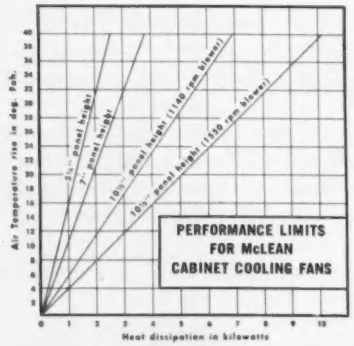
use McLEAN *Cabinet Cooling* FANS and BLOWERS*

*Pat. Applied For

RACK MOUNTED FOR EASY ASSEMBLY • FIT STANDARD 19" RACKS

THREE STANDARD MODULAR PANEL HEIGHTS COVER WIDE RANGE OF AIR DELIVERIES

Excessive or fluctuating temperatures in electronic racks make thousands of tubes die young . . . make crystals, transistors and sensitive electronic equipment perform erratically. System failure at critical times is disastrous . . . replacement costs are high. That is why leading manufacturers install McLean Fans and Blowers in Computers, Control Systems, Data Processing Systems, etc. These small packaged units pressurize the cabinet with cool filtered air, keeping dust out. They are complete in one unit and ready for use. Standard RETMA notching allows mounting on rack . . . no cutting or fitting is necessary. All units contain an easily replaceable filter. Smart stainless steel grilles add beauty and eliminate the necessity of matching cabinet finishes.


Air Temperature rise in deg. Fah.
Heat dissipation in kilowatts
3½" panel height
7" panel height
10½" panel height (1140 rpm blower)
10½" panel height (1550 rpm blower)
PERFORMANCE LIMITS FOR McLEAN CABINET COOLING FANS

SPECIFICATIONS

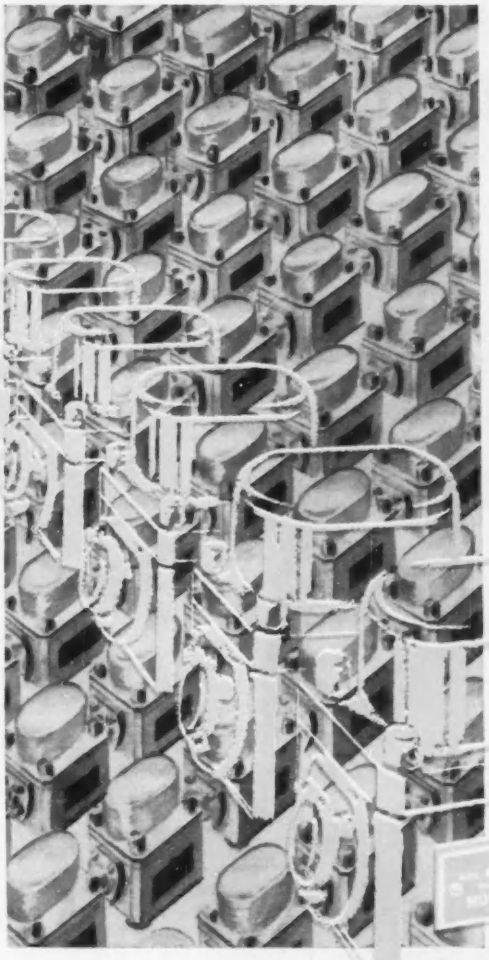
PANEL HEIGHT	MODEL	DEPTH	CFM	REMARKS	TYPE
5¼"	2A300	7½"	80	Standard Rack Mounting	Blower
	2E300	7½"	80	For Trim Strip Racks	Blower
	2B300	7½"	150	Basic Model	Blower
	3E40	5⅞"	190	For Special Clearance	Propeller
	2P408	11⅛"	300	Inside Height 7"	Blower
7"	2E55	8¼"	250	Basic Model	Propeller
	2E408	10"	300	Basic Model	Blower
	2A408	8¼"	300	No Projecting Outlets	Blower
	2E408V	8¾"	300	Vertical Discharge	Blower
	2E55H	8¼"	310	400 cps Model	Propeller
10½"	2E80	8⅛"	500	Basic Model	Propeller
	2B610	13¼"	550	Slow Speed Model	Blower
	2A610	13¼"	800	22" Rack Width	Blower
	2E610	13¼"	800	Basic Model	Blower

MODIFICATIONS OF ABOVE MODELS CAN BE MADE TO 24" OR SPECIAL WIDTH RACKS TO ORDER

FREE OUR NEW CONDENSED CATALOG! *SEND FOR IT TODAY.*

McLEAN ENGINEERING LABS. PRINCETON, NEW JERSEY
PHONE: PRINCETON 1-4440

Agents in all principal electronic manufacturing areas.



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Over 40,000 Moog electro-hydraulic mechanisms . . . comprising more than 700 specific models . . . have been produced. Each model has been designed to definitive specifications by Moog's highly creative engineering staff. This quantity affirms the high quality, reliability and efficient volume production through which Moog Servo Valves have achieved industry leadership. For competent assistance in solving your hydraulic servo problems, call on Moog's experienced design engineering team.

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MOOG VALVE CO., INC. PRONER AIRPORT, EAST AURORA, NEW YORK

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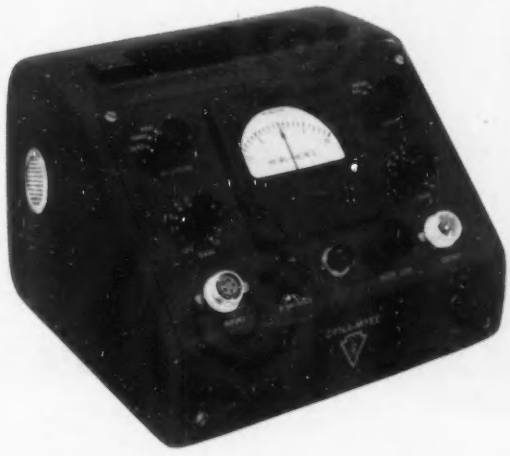
SERVOMECHANISMS INC. SMI

Industrial Electronics' DYNA-MYKE Model 129-E

High-Speed, Precision, Dynamic Measurement



A complete system for linear variable differential transformers and strain gages

- Single Unit Control System for LVDT's and Strain Gages
- Direct Reading of Static Displacements
- Provision for Dynamic Recording
- High Level, Low Impedance DC Output
- High-Speed Gaging and Control
- Universal System of Measurement

DYNA-MYKE is a high speed, precision, dynamic carrier amplifier micrometer. It supplies a complete measurement and control system for linear variable differential transformers and strain gages. Displacements as small as plus or minus one micro-inch at frequencies as high as 1000 cps can be detected and indicated. DYNA-MYKE carrier system energizes the transformers or strain gages at 8000 cps. Provision is made for balancing the carrier to mid-zero position on the meter. The modulated carrier may be fed into an oscilloscope; the demodulated signal into an indicator, recorder, relay, servo valve or servo-motor. The system of measurement is universal. Basic engineering phenomena such as force, torque, strain, vibration, acceleration, temperature, pressure, and displacement may be indicated and recorded, or used as a control function for high-speed automated applications.*

DYNA-MYKE is designed for use with commercially available pickups for measuring pressure, displacement, vibration and acceleration using linear variable differential transformers, strain gages, and inductive or resistive bridges as transducers. Custom pickups are designed and constructed by Industrial Electronics, Inc.

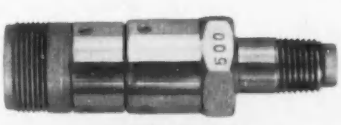
The light-weight, packaged unit is enclosed in an attractive, durable cast aluminum case.

**Ruggedized modular plug-in carrier systems conforming to Dyna-Myke specifications are also available for industrial plant installations. Write for information on company letterhead.*

SPECIFICATIONS

Using Schaevitz 100ML LVDT: 2MV/V/.001 inch gage constant.
5 Ranges of Measurement 0.00001 inch to ± 0.1 inch full scale
Sensitivity, Maximum—0.0000005 inch per meter division
System Frequency Response—DC to 1000 cps (down 3 db at 1500 cps.)
Carrier Frequency—8 kc, ± 2%
Carrier Voltage—Max 24 volts RMS, 20 volts RMS in 1000 ohms.
Maximum Gain, Overall 150,000 (RMS input to DC output)
Zero Drift, Maximum—± 1% per hour after warmup
Instrument Stability—± 2%
Repeatability of Measurement (Short time)—± 0.5% or better
Output Current, Maximum Linear—± 12 ma. in 1,500 ohms
Output Current, Maximum ungrounded—± 35 ma. in 25 ohms
Output Impedance—450 ohms
Output Voltage, maximum (no load) ± 25 volts
Power—105 watts, 90-130 volts, 60 cps
Weight—22 lbs.
Dimensions—12¼ x 10 x 7½ inches

Calibration Signal Independent of Transducer Is Internally Provided.



PRESSURE PICKUP
Model 125-M

GAGE HEAD
Model 194

ACCELEROMETER
Model 5-B

BALANCE BOX
Model 204

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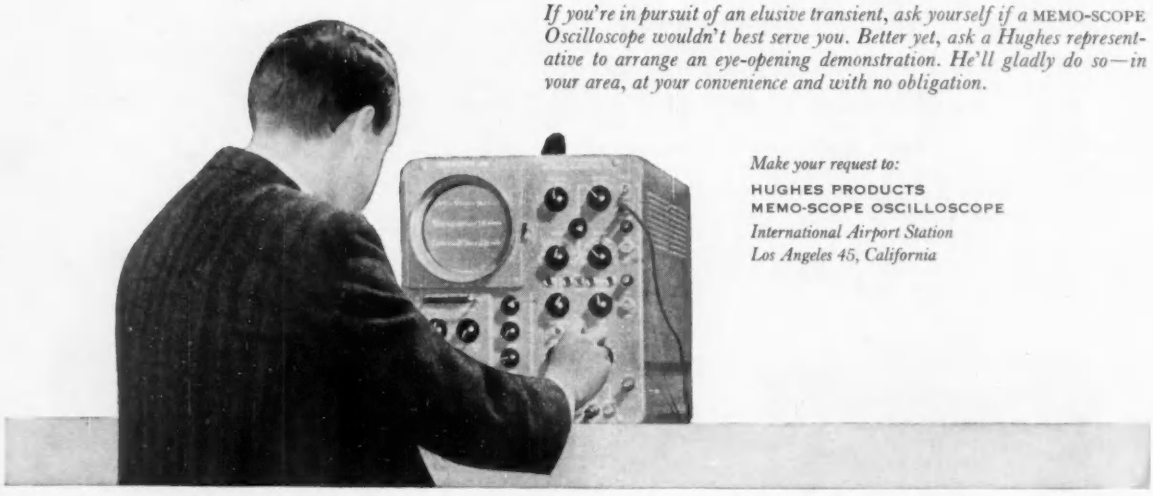
Introducing Number **1** *of a Factual Series about the Hughes* MEMO-SCOPE* *Oscilloscope*

MAN-DAYS SAVED

in research and testing involving transients

We are pleased to report a major breakthrough by a Hughes product that will significantly reduce the monotonous man-days spent pursuing elusive transients. Practically a promise of all things to all men in research and testing procedures involving traces, this new instrument of benefaction is the Hughes MEMO-SCOPE* Storage-Type Oscilloscope. A transient recorder with a "memory" it can retain single or successive writings for an *infinite length of time or until intentionally erased.*

Heretofore, the tedious trial and error methods and repetitious hair-trigger photography necessary to "capture" transients on conventional scopes has mercilessly wasted time, film and precious effort, not to mention ruffling dispositions. But, never again. Now, you may instantly "freeze" any number of selected wave forms in brilliant clarity on the face of a MEMO-SCOPE Oscilloscope —study, compare and analyze them at leisure. Or if desired, take convenient photographs with just one camera setting—one exposure—for each permanent record required. Superbly engineered and completely electronic, MEMO-SCOPE Oscilloscope involves no slide wires, no bothersome paper and ink problems.



If you're in pursuit of an elusive transient, ask yourself if a MEMO-SCOPE *Oscilloscope wouldn't best serve you. Better yet, ask a Hughes representative to arrange an eye-opening demonstration. He'll gladly do so—in your area, at your convenience and with no obligation.*

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surface barrier transistors from SPRAGUE

high speed transistors for computer switching circuits

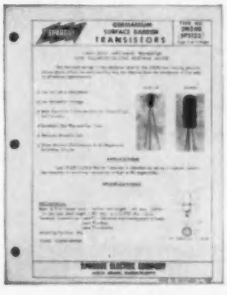
Sprague 2N240 Transistors with their fast response time—in the millimicrosecond range—give reliable operation in switching circuits up to 20 megacycles. The ideal electrical characteristics of these surface barrier transistors permit direct coupling for faster operation than any alloy junction type.

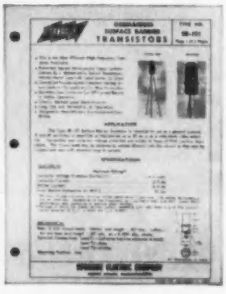
And the 2N240 gives you:

- low saturation resistance
- low saturation voltage
- extremely fast rise and fall time
- absolute hermetic seal
- availability

Among these features, the most important to you may well be availability. Sprague is manufacturing 2N240 Transistors NOW in production volumes. You can answer today's transistor needs *today* by specifying Sprague Surface Barrier Transistors!

Write for complete data sheets on Sprague 2N240 Germanium Surface Barrier Transistors and on Sprague General Purpose High-Frequency Surface Barrier Types 2N344/SB101, 2N345/SB102, 2N346/SB103. All are available on letterhead request to the Technical Literature Section, Sprague Electric Co., 407 Marshall St., North Adams, Massachusetts.





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complete central operating control of analog computers

with the new REAC®

AUTO-CONTROL SYSTEM

Here in brief are the capabilities of this new auto-control system.

From typed command or punched tape

Set any scale factor or problem check pot under load. • Read out setting of any scale factor or problem check pot under load. • Read actual voltage of any pot under load. • Measure voltage at any amplifier or selected point in computer. • Put computer into any operating mode.

Auto-cycle automatically reads out

All amplifiers. • All integrators. • All scale factor pots onto tape or hard copy. • All problem check pots onto tape or hard copy. • All amplifiers *and* all pots, as above. • Auto-set all pots to zero . . . and, in addition, the system permits automatic programming of computer operation.

Increases time computer is available for actual running of problems.

Not a press agent's dream, nor an artist's conception, but an actual working system, this new REAC Auto-Control System is showing the way to new levels of analog computer efficiency. Used in conjunction with the REAC Problem Check, Time Scale Check and Voltage Scale Check Systems, it allows a problem to be inserted and checked out in a fraction of the normal time. Problems can be taken off and reinserted fast enough so that trouble-shooting of computer problems, re-scaling of time and voltage parameters, and preliminary evaluation of results can be done while the machine is busy on another problem. Multi-shift operation becomes really practical, too.

The REAC Auto-Control System adds a completely new dimension to the analog computer technique. Write for complete details on what it can mean to you.

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REAC Analog Computers

Precision Floated Gyros

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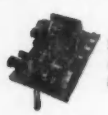

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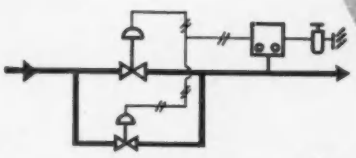
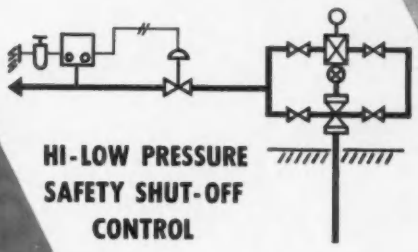
For Optimum Pressure Control, Specify BS&B 72-14 Pressure Controllers And Transmitters!

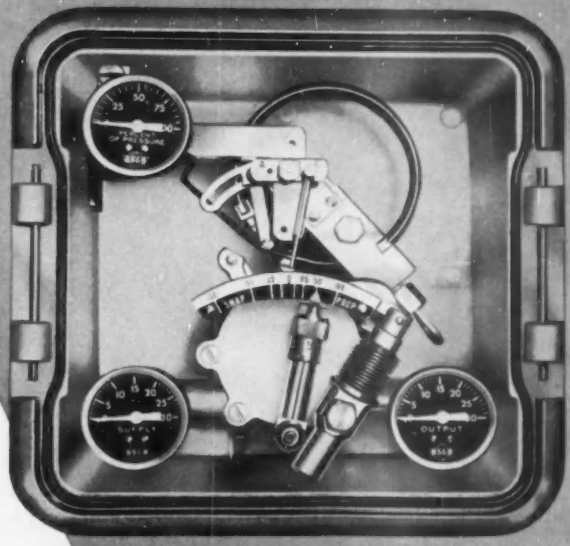
Proportional * On-Off * Differential Gap
Indicating Or Non-Indicating

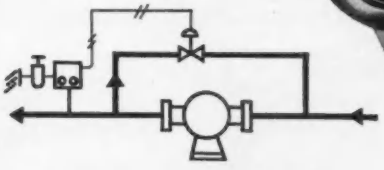


PRESSURE REDUCING CONTROL



HI-LOW PRESSURE SAFETY SHUT-OFF CONTROL

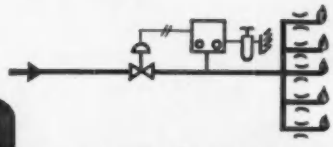




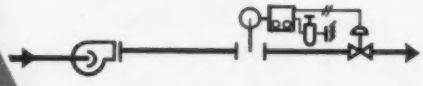
BACK PRESSURE CONTROL

FEATURES OF POWER UNIT:

- Three-To-One High Capacity Relay
- Vibration Proof
- Push Button Cleanout
- Factory Calibrated Feed-Back Bellows
- Micrometer Adjustment



LOW PRESSURE CONTROL



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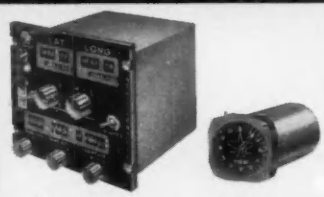
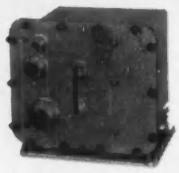
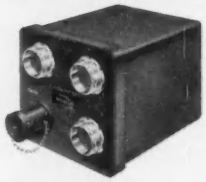


FICo ASN-7 Course and Distance Computer System — indicator and control are shown. Can be provided with polar capabilities.



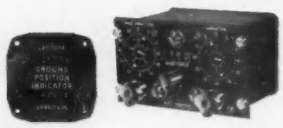
FICo Viewfinder Computing Timer — controls up to five aerial cameras simultaneously. Highly compact.

FICo Exhaust Temperature Indicator — range 200°C to 1000°C with ±5° accuracy. 6″ long x 2″ diam.



FICo Wind Memory Computer — an aid when navigational systems operate with Doppler.

FICo Magnetic Variation Computer — precludes need for manual correction in aero navigation.

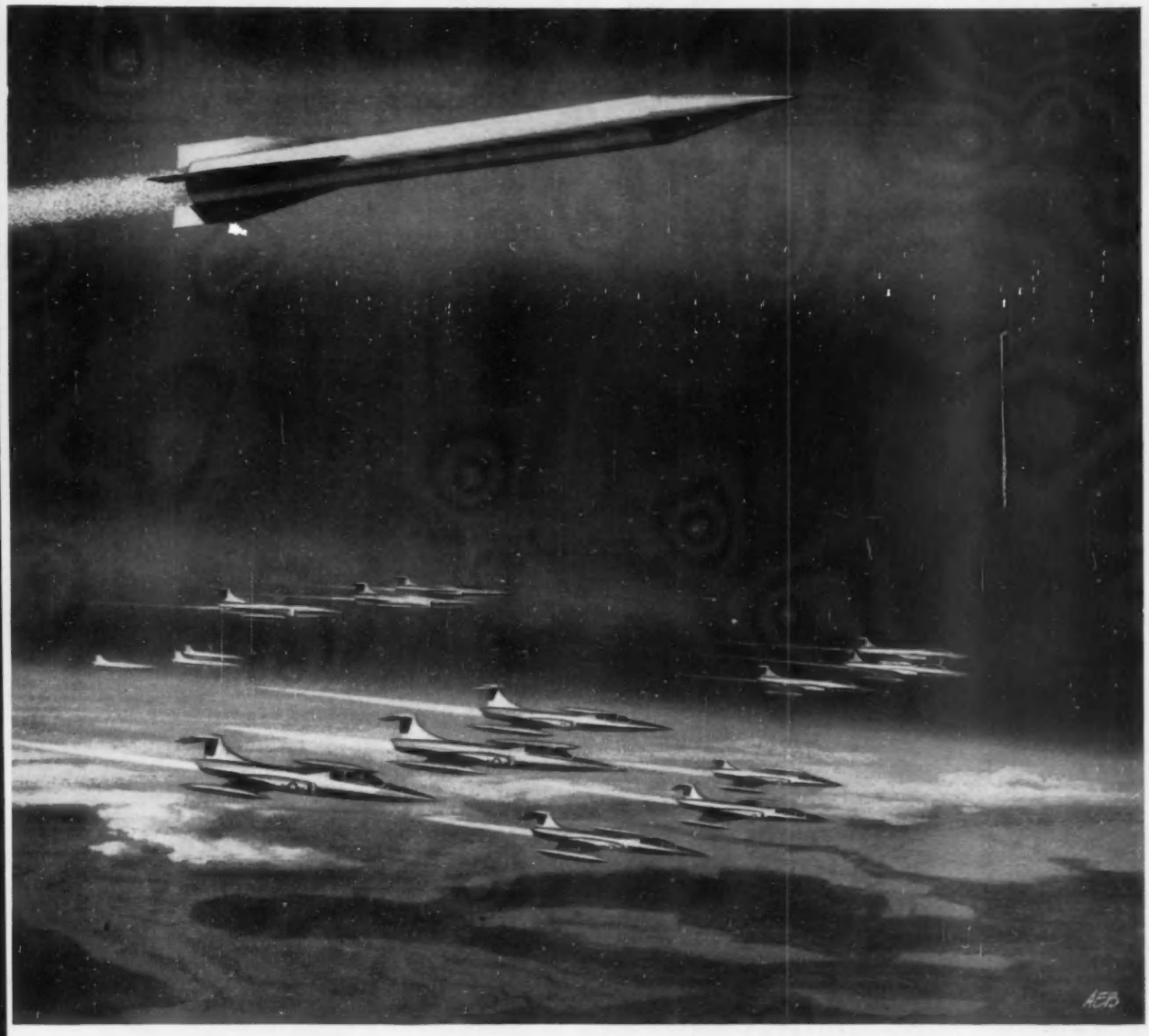


FICo ASN-6 Present Position Computer System — indicator and control are shown.

No missile systems can be illustrated because of the level of classification. FICo is doing extensive work in ABMA's Redstone and Jupiter programs, in the Navy's Tartar and Terrier programs, and in other projects.

FICo Test Set — for flight line check out of navigational system. Self-contained and portable.

FICo Analog-to-Digital Converter — for airborne sensing system for traffic control.



Ford Instrument provides the systems

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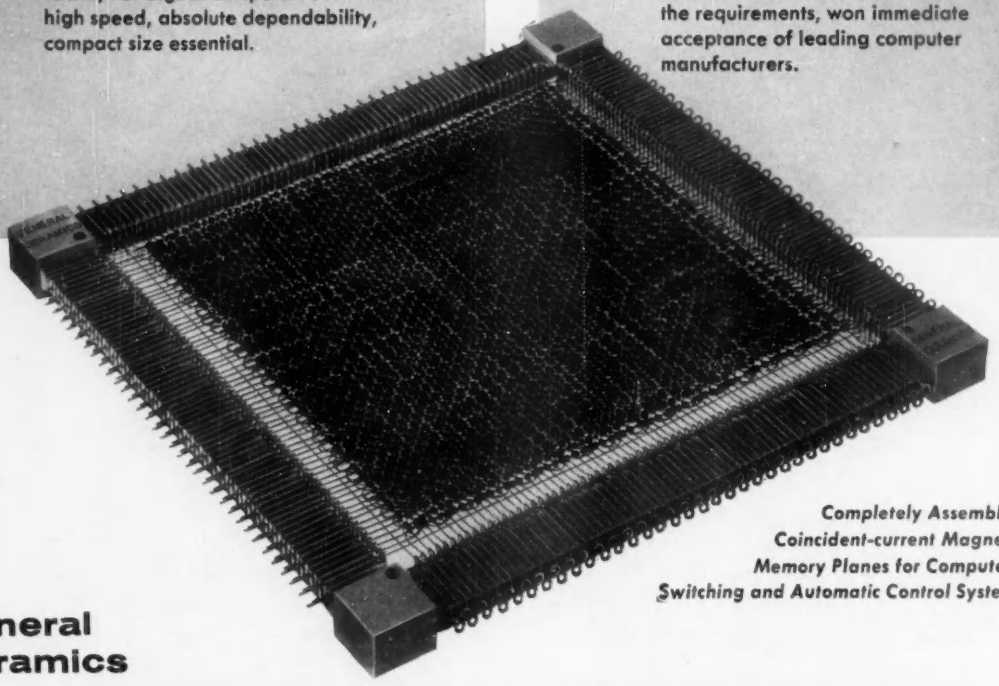
For information on FICo's aero and missile products and capabilities, write to FICo's AIRBORNE EQUIPMENT DEPARTMENT.

PROBLEM:
Provide a reliable memory storage facility for digital computers . . . high speed, absolute dependability, compact size essential.

SOLUTION:
Magnetic Core Memory Planes by General Ceramics . . . far exceeded the requirements, won immediate acceptance of leading computer manufacturers.



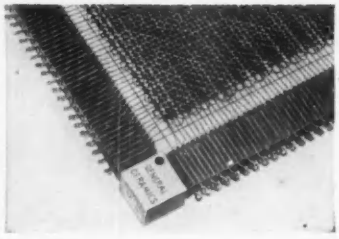
Completely Assembled Coincident-current Magnetic Memory Planes for Computers, Switching and Automatic Control Systems

General Ceramics

FERRAMIC® MAGNETIC MEMORY PLANES

Utilizing Ferramic Magnetic Memories resulted in important increases in reliability, speed and accuracy in actual operation. In addition, designers found space requirements sharply reduced. Lower power consumption, lighter weight, elimination of heat dissipating devices and *greatly reduced* maintenance were other significant improvements.

General Ceramics Magnetic Memories offer a solution to similar problems in automatic control systems for conveyors, elevators, telephony, production machines, processing equipment and signalling. For further details, write General Ceramics Corporation, Keasbey, New Jersey. Please address inquiries to Dept. CE.



Completely assembled standard type memory frames available from stock. Memory Frames of special design can be produced to your specifications.

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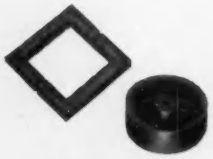
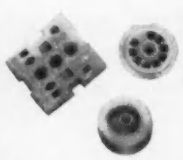
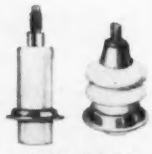


FERRAMIC CORES

FERRAMIC MAGNETIC CORES



PRECISION STEATITES



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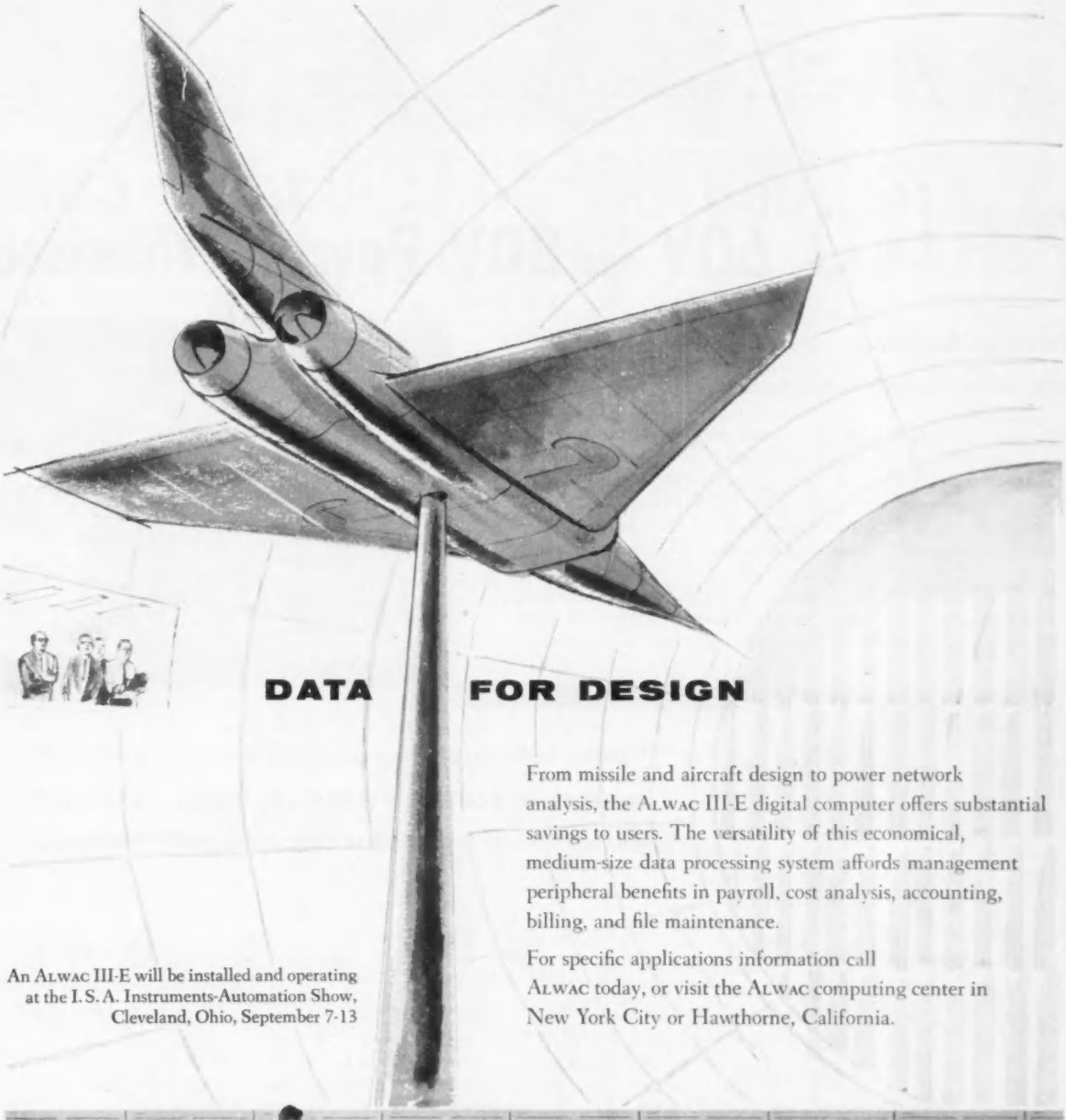
SOLDERSEAL TERMINALS



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An ALWAC III-E will be installed and operating at the I. S. A. Instruments-Automation Show, Cleveland, Ohio, September 7-13

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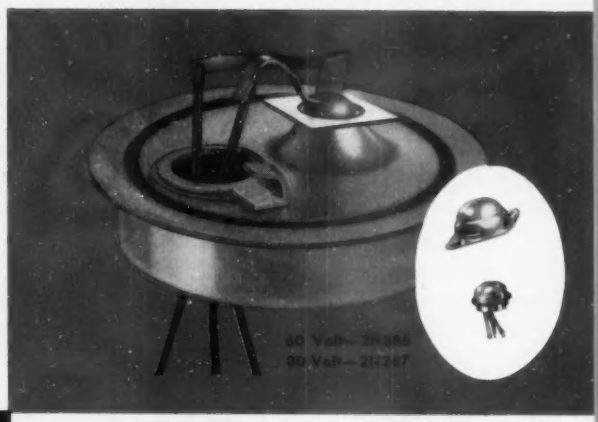
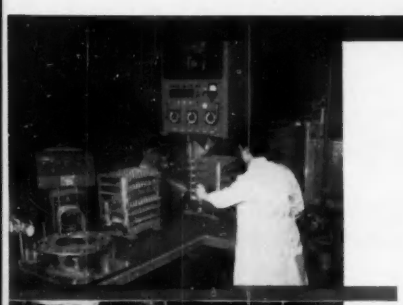
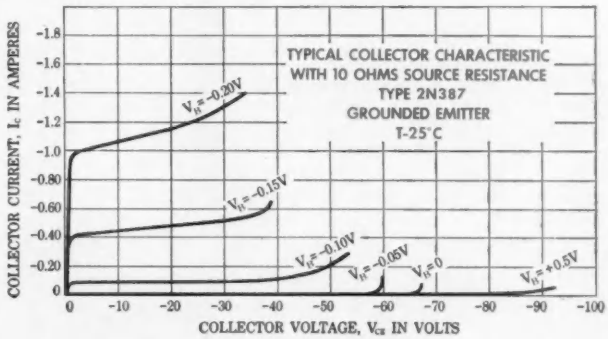
Designed for servo, control, power converter and power supply applications.

Here are extremely reliable, high voltage power transistors—immediately available in production quantities. These transistors perform with a typical thermal drop of only 1½°C per watt . . . with storage temperature of 100°C. They have high beta at high currents . . . improved alpha cut-off . . . low surface leakage currents . . . low saturation resistance . . . low distortion. Both transistors operate at power load of 12.5 watts. The unique *knee-action* between the aluminum mounting clamp and the copper mount assures maximum dissipator contact at all times. Recent price reductions make these transistors the greatest value in the high voltage power transistor field.





Philco cold-welding process permits hermetic sealing in controlled atmosphere... assuring exceptional transistor life and performance!



Philco transistors, after vacuum baking, emerge into a controlled atmosphere . . . where they are welded to insure perfect sealing for life. This process eliminates contamination of the transistor elements by moisture or atmosphere. Uniformity and quality control are strictly maintained throughout.

Write for complete data, application notes on voltage ratings of power transistors, and new low prices to Lansdale Tube Company, Lansdale, P

PHILCO CORPORATION

LANSDALE TUBE COMPANY DIVISION

LANSDALE, PENNSYLVANIA

Progress Report:

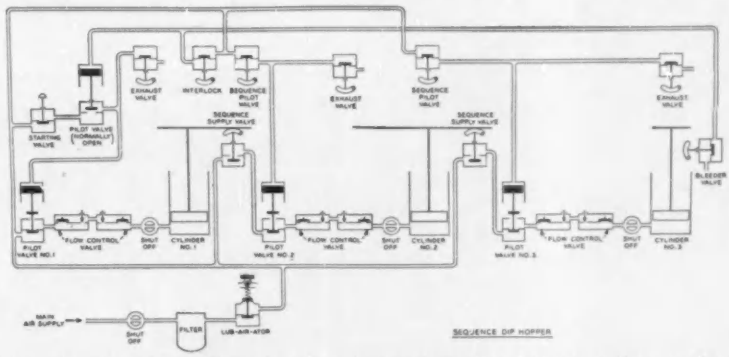
SCHRADER AIR PRODUCTS PERFORM JOBS IN SEQUENCE—AUTOMATICALLY

• Don't send a boy to do a man's job

When you say that, smile, if you're talking about air. Air can do *more* than a man's job. It can perform complicated, time-consuming operations faster, more accurately, and much more economically than *any* man.

There was a time when air power was used for nothing but simple one-shot actions, but those days are far behind. Now, automation has brought air so far beyond the "bellows-in-the-forge" age that the contrast is startling.

Manufacturers who think of Schrader Air Products only for the so-called simple-minded jobs are missing out on one of the true revolutions of our times. Their competition is using air systems, on the other hand, to make precision operations to close tolerances, for operations in sequence, and you can't blame them if they're a little smug about the amazing effectiveness, economy, and safety they've developed.



Schematic shows how a Schrader air system operates for plated part dippers, shortening the cycle, and releasing operators for more useful jobs.

FOR EXAMPLE:

• This job was driving sane men off their rockers

Until recently, the toughest job at a New Haven plating company was dipping baskets of plated parts in three successive baths. The triple bath sequence was not just monotonous – it was slow, expensive, in a corrosive atmosphere, and calculated to frazzle the tempers of workers. Then the operation was automated with Schrader Air Products. The dip hoppers now operate as if by magic—in solitary splendor. Completion of one sequence automatically starts another.

The schematic on this page is eloquent. Combinations of Schrader cylinders, pilot valves, two way valves, and flow control valves have been engineered into a true automated sequence system. Once again, open-minded engineers discovered the best way—air—had definite advantages.

• What you don't know can hurt you

Most engineers already know that Schrader Air Products are available NOW, that the products are designed to be fitted together as simply as an Erector set, and that the hundreds of different parts available offer capabilities that are virtually limitless. Advantages? Well, here they are again: Exceptional economy is basic. Safety margins can be widened by the use of special control techniques. Simplicity of air systems allows fingertip-push-button-tiptoe operations that are fatigueless. Production is speeded up.

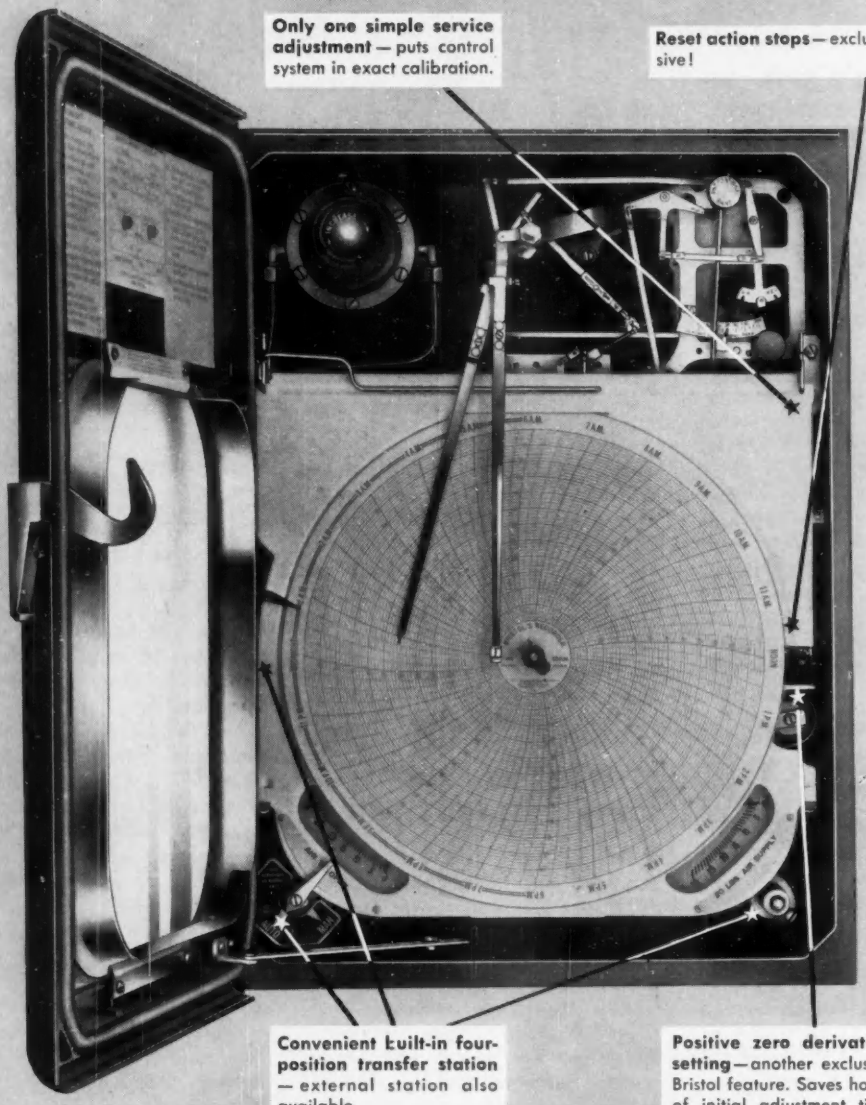
• Take a good look at yourself

Better yet, let *us* look you over. Schrader engineers will be happy to assist you in planning for the most efficient use of air in your plant. And they'll be glad to recommend products which most readily suit given applications . . . even packaged control sets that are so perfected that most press hazards are eliminated. Both hands must be used at once and can't get into mischief. Any machine using mechanical clutch, shears, brakes and friction clutches can use special controls. You may be very surprised at how painlessly Schrader can turn your idea into fact. Information is available by writing directly to us . . . and our distributors are conveniently located for fast delivery. Address A. Schrader's Son, Division of Scovill Mfg. Co., Inc., 471 Vanderbilt Avenue, Brooklyn 38, N. Y.

Schrader®
a division of SCOVILL

QUALITY AIR CONTROL PRODUCTS

Are you sure you


Only one simple service adjustment — puts control system in exact calibration.
Reset action stops — exclusive!
Convenient built-in four-position transfer station — external station also available.
Positive zero derivative setting — another exclusive Bristol feature. Saves hours of initial adjustment time for difficult processes.

MADE IN MODELS FOR THESE CONTROL MODES:

1. **Fixed narrow band** (on-off).
2. **Proportional**—to 100% and to 30%.
3. **Reset with wide band**—rates 0.1 to 10 or 1 to 300 repeats per minute. Proportional band to 400%.
4. **Derivative** (rate)—Derivative time 0.2 to 20 min., plus zero derivative setting.
5. **Reset plus derivative**—proportional band, reset rate and derivative time as shown above.

WILL HANDLE THESE CONTROL PROBLEMS:

1. Cascaded control
2. Selective control
3. Ratio control
4. Time-program control
5. Pneumatic transmission.

are getting the best in pneumatic controllers?

Before you buy another controller check these advantages of the new Bristol Series 500 Free-Vane® Pneumatic Controller

FINEST MEASURING ELEMENTS

Bristol Series 500 Pneumatic Controllers are equipped with precision Bristol measuring elements—the widest selection of high-quality measuring elements available with any line of control instruments. You'll find models for control of: **temperature, pressure, vacuum, draft, absolute pressure, liquid level, flow, humidity, density, pH, and a large number of other variables measurable with electronic potentiometers and bridges.**

The sustained, predictable performance of Bristol measuring elements is one reason why you'll find more Bristol recording pressure gauges in use *than all other makes combined.* The new, completely linear Bristol Dual-Filled Vapor Pressure Measuring Element used in Series 500 Thermometer Controllers is the first really big advance in this field of measurement in 25 years. The Bristol Absolute Pressure Element, available in ranges as low as 0-6 mm of mercury absolute, also leads in its particular field. These are just a few of many examples of Bristol leadership in the development and improvement of measuring elements.

ADVANCED CONTROL SYSTEM FEATURES

Many features *found on no other pneumatic controller* assure better control with the Bristol Series 500: Reset action stops on reset models prevent loss of control due to prolonged deviation from set point; true zero derivative setting (on derivative models) can save hours of initial adjustment time; easy shift to wider proportional band (½ to 200% or 1 to 400% on wide band models) *without recalibration.*

BEST MAINTENANCE RECORD

One simple adjustment puts a Series 500 controller in exact calibration.

Basic simplicity, accurate design, closely held manufacturing tolerances make this single adjustment all that's necessary—even after complete disassembly and reassembly with replacement parts.

Bristol Series 500 Controllers on the job in new modern processing plant. Absolute pressure, steam flow, and liquid levels are variables controlled here.

This practically "built-in" calibration is typical of the foresight and engineering planning that make the Series 500 the easiest pneumatic control system on the market to service. Cut-and-try methods are eliminated. No special maintenance skills are required. All parts are completely interchangeable. The result: a truly superlative maintenance record in thousands of industrial plants.

NATION-WIDE SERVICE

Series 500 Controllers are backed up by the kind of service a quality product requires. The facilities of the main factory, four strategically-located branch factories, and factory-trained service engineers operating out of 44 principal cities across the United States and Canada are on call whenever and wherever needed to help you get the most out of your Bristol Pneumatic Controllers.

GET COMPLETE INFORMATION

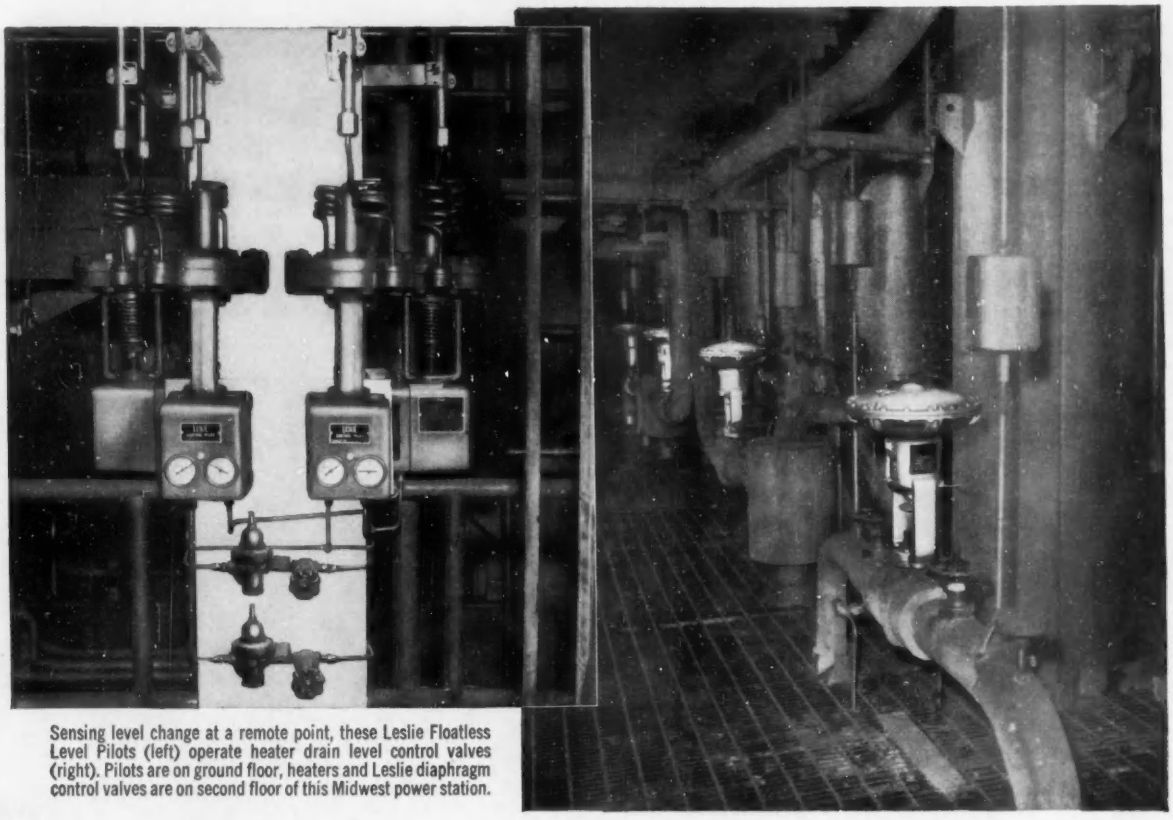
. . . on the Bristol Series 500 Pneumatic Controller before you buy another instrument! Fully described in Bulletin A130. Write: The Bristol Company, 101 Bristol Road, Waterbury 20, Conn. 6.76

*T.M. Reg. U. S. Pat. Off.

BRISTOL *TRAIL-BLAZERS IN PROCESS AUTOMATION*

Come and see us at the I.S.A. Show in booths 918 thru 930

AUTOMATIC CONTROLLING, RECORDING AND TELEMETERING INSTRUMENTS



Sensing level change at a remote point, these Leslie Floatless Level Pilots (left) operate heater drain level control valves (right). Pilots are on ground floor, heaters and Leslie diaphragm control valves are on second floor of this Midwest power station.

differential pressure method offers

STABLE, FASTER-SENSING LEVEL CONTROL

Because the Leslie Level Control Pilot uses the differential method for sensing changes in liquid level, it receives its impulse changes faster than any other type of level control. You can install it *anywhere* below liquid level, mounted on the valve, or at a point remote from vessel or valve. Used on either open or pressurized vessels, it controls the level of virtually any liquid including water, gasoline, oil, alcohol, solvents, chemical solutions and acid.

And It's Floatless, too!

There are no floats, torque tubes, seals, stuffing boxes or thermal-hydraulic tubes which are affected by turbulence, wear or temperature changes. Installation is fast and uncomplicated. Simple spring adjustment changes set point. Maintenance free, rugged "high impact" design is unaffected by shock. The only *one* moving element is virtually frictionless . . . its total movement is only .006".

Responds Fast . . .

A high air loading capacity in the Leslie Control Pilot means a fast response with a smooth, throttling action free from hunting or cycling.

More Information

Ask your Leslie engineer to give you the complete story of the exclusive features that make Leslie Control Pilots ideal for level control problems. He's listed in your classified telephone directory under "valves" or "regulators"

Send for the engineering data bulletin No. 5303.

TRADE LESLIE MARK

REGULATORS AND CONTROLLERS

LESLIE CO., 211 GRANT AVENUE, LYNDHURST, NEW JERSEY

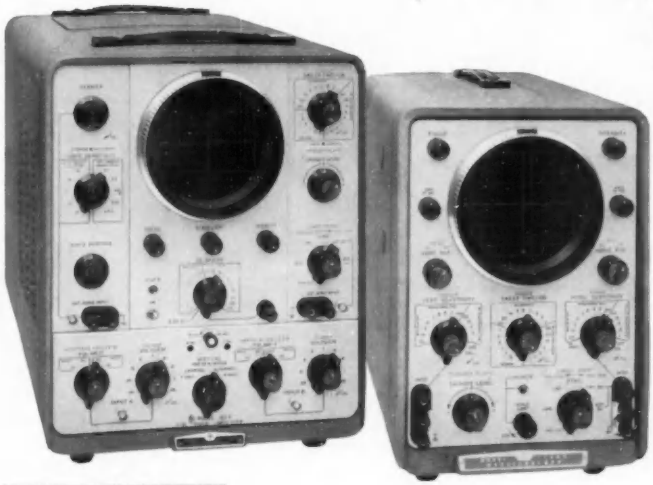
608

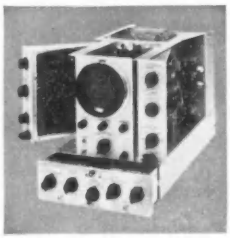
Electronic Test Equipment for CONTROL ENGINEERING

-hp- Low Frequency, High Frequency Oscilloscopes

-hp- 150A High Frequency Oscilloscope

Dc to 10 MC. Plug-in pre-amplifiers.
Sweeps 0.02 μsec/cm to 15 sec/cm





-hp- 130A Low Frequency Oscilloscope

High sensitivity, dc to 300 KC.
Sweeps 1 μsec/cm to 12 sec/cm

Never before in *-hp-* history have two instruments gained such immediate and wide-spread usage as the all-new *-hp-* oscilloscopes.

Based on a completely fresh philosophy of oscilloscope design, new *-hp-* 130A and 150A establish new standards of oscilloscope usefulness, convenience, dependability. Important feature is universal automatic triggering arrangement where one preset adjustment provides optimum triggering for most conditions. Other appreciated features include direct-reading calibrated sweeps, brilliant, high resolution trace without halo or bloom, etched circuits with unitized construction, concentric, color-coded controls, highest quality components and ultra conservative design, twistoff bezel, easy CRT or filter interchange, tilt bail.

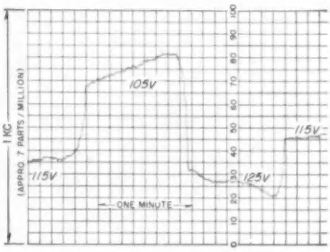
***-hp-* 150A, dc to 10 MC,** has plug-in vertical amplifiers offering either high gain or dual trace. The instrument sweeps 0.02 μsec/cm to 15 sec/cm; there are 24 direct reading calibrated sweep ranges. May be triggered internally, by line voltage, or externally. Horizontal amplifier's magnification feature expands horizontal sweep 5, 10, 50 or 100 times. Vertical amplifier has rise time of less than 0.035 μsec; signal delay permits leading edge of triggering signal to be viewed. For maximum flexibility; 18 calibrating voltages in 2, 5, 10 sequence, 0.2 mv to 100 v peak-to-peak, are available at the front panel.

***-hp-* 130A, dc to 300 KC,** has similar vertical and horizontal amplifiers with sensitivity 1 mv/cm to 50 v/cm. Instrument sweeps 1 μsec/cm to 12 sec/cm, may be triggered internally by line voltage, or by a 0.5 volt or larger external source. 21 sweep times may be directly set; no interpolation required. Includes input attenuator with calibrated ranges in 1, 2, 5, 10 sequence; continuous adjustment vernier between ranges. Attenuator, plus instrument's high stability, permits use of 130A as millivoltmeter or voltmeter accurate to within 5%.

***-hp-* Model 130BR** is similar to the 130A but is designed specifically for rack mounting. This instrument has a x5 magnifier for all internal sweeps increasing the fastest sweep time to 0.2 μsec/cm.

Instrument	Primary Uses	Characteristics	Price
-hp- 130A	General laboratory and production testing	Dc to 300 KC—High sensitivity	$ 650.00
-hp- 130BR	Rack mount, similar to -hp- 130A	Dc to 300 KC—High sensitivity	650.00
-hp- 150A	General laboratory high frequency and TV work	Dc to 10 MC—Plug-in vertical amplifiers	1,100.00
-hp- 150AR	Rack mount, similar to -hp- 150A	Dc to 10 MC—Plug-in vertical amplifiers	1,200.00
-hp- 151A	High sensitivity—Plug-in for 150A	Dc to 10 MC—High sensitivity	200.00
-hp- 152A	Dual Trace—Plug-in for 150A	Dc to 10 MC—Presents two phenomena for simultaneous viewing	250.00

New -hp- 560A Digital Recorder



Frequency stability vs. line voltage; 150 MC oscillator

New *-hp-* 560A provides a continuous digital record for your *-hp-* frequency counter. Since 560A is a slave to its counter, it delivers accuracy identical with counter. Printing rate is five, 11-digit lines per second. Secondary or coding data may be printed on the same line as primary data. Instrument may be controlled by electronic or electromechanical devices; it includes an analog output for strip chart recorders; strip chart will never be driven off scale. Expanded scale recordings may be made with full scale sensitivity as great as $1/10^7$.

-hp- 560A, $1,390.00 (11-digit lines)

-hp- 560A, $1,265.00 (6-digit lines)

Other -hp- Frequency Measuring and Monitoring Equipment

-hp- 500B/C Frequency Meters

Directly measures frequency of voltages 3 cps to 100 KC; expanded scale allows any 10% or 30% of range to be measured full scale. Sensitivity 0.2 v rms (sine waves) 1 v peak for pulses. Input impedance 1 megohm with 40 $\mu\mu$f shunt; accuracy independent of line voltage changes. Also available as *-hp-* 500C, calibrated for direct reading in rpm. *-hp-* 500B/C, $285.00.

-hp- 521A/C Industrial Counters

Most useful, accurate, low cost industrial counter. Measures frequency, speed, rpm, random events, other phenomena. Direct readings 1 cps to 120 KC. Time of count 0.1 or 1.0 seconds; variable display time. Also offered as 521C, 5-place registration, three gate times, crystal-controlled time base. *-hp-* 521C, $650.00. *-hp-* 521A, $475.00.

-hp- 522B Electronic Counter

Compact, low cost, versatile instrument for frequency, period *or* time measurements. Measures frequency 10 cps to 120 KC, time interval 10 μsec to 10^8 sec. Reads direct in cps, KC, seconds or milliseconds. Count automatically reset, action repetitive. Stability of time base 10/1,000,000 per week. Easily used by untrained personnel. $915.00△.

-hp- 523B Electronic Counter

Revolutionary all-purpose counter measures frequency 10 cps to 1.1 MC, time interval 3 μsec to 27.8 hours, period 0.00001 cps to 10 KC. Stability 2/1,000,000 per week. Results displayed in sec, msec, μsec or KC; automatic decimal. Display time variable 0.1 sec to 5 sec or indefinitely. Accuracy ±1 count plus crystal stability, 5 gate times. Usable with 100 KC primary standard. $1,175.00.

Instrument	Primary Uses	Frequency Range	Characteristics	Price
-hp- 100D Secondary Standard	Frequency, time measurements	100 KC, 10 KC, 1 KC, 100 cps, 10 cps	Stability 1/1,000,000 (short-time). Sine or rectangular output. Marker pips	$ 615.00△
-hp- 335E TV Monitor	Aural and visual carrier monitoring; black and white or color	Channels 2 to 83	Aural deviation ±3 KC; video deviation ±3 KC; accuracy ±500 cps approx.	2,050.00
-hp- 500B Electronic Frequency Meter	Rapid frequency measurements	3 cps to 100 KC	9 ranges ±2% accuracy. Input 0.2 to 250 volts	285.00
-hp- 500C Electronic Tachometer Indicator	Rpm measurements	180 to 6,000,000 rpm	Similar to 500B but calibrated in rpm	285.00
-hp- 506A Optical Tachometer Pickup	Rps and rpm measurement	300 to 300,000 rpm	Phototube and light source; output 1 v rms	100.00
-hp- 508A Tachometer Generator	Shaft speed measurement	15 to 40,000 rpm	Output 60 cycles per revolution	100.00
-hp- 508B Tachometer Generator	Shaft speed measurement	15 to 40,000 rpm	Output 100 cycles per revolution	100.00
-hp- 508C Tachometer Generator	Shaft speed measurement	15 to 40,000 rpm	Output 120 cycles per revolution	100.00
-hp- 508D Tachometer Generator	Shaft speed measurement	15 to 5,000 rpm	Output 360 cycles per revolution	100.00
-hp- 520A Nuclear Scaler	For counting high-rate pulses	Capacity 100 counts in 2 decades. 10,000,000 pps counting rate	100:1 divider for operation of low speed scalers	615.00△
-hp- 521A Industrial Electronic Counter	Measure frequency, speed	1 cps to 120 KC	Direct reading, accurate within ±1 count ±0.1%, 4 place registration	475.00
-hp- 521C Industrial Electronic Counter	Measure frequency, speed	1 cps to 120 KC	Direct reading, accuracy within ±1 count ±0.01%, 5 place registration	650.00
-hp- 522B Electronic Counter	Frequency, period, time interval measurements	10 cps to 120 KC	Direct reading, accuracy ±1 count ±0.001%	915.00△
*-hp-*523B Electronic Counter	Frequency, period, time interval	10 cps to 1.1 MC	Direct reading, accuracy ±1 count ±2/1,000,000	1,175.00

△Rack mounted instrument available for $15.00 less.

-hp- Vacuum Tube Voltmeters—10 to 700,000,000 cps

-hp- 400D Vacuum Tube Voltmeter

Best -*hp*- voltmeter ever built! Covers all frequencies 10 cps to 4 MC. Extremely sensitive, wide range, accurate within 2% to 1 MC, measures 0.1 mv to 300 v. Direct reading in dbm. 10 megohm input impedance insures negligible loading on circuits under test. New amplifier circuit with mid-range feedback assures utmost stability, freedom from change due to external conditions. $225.00.

-hp- 410B Vacuum Tube Voltmeter

All-purpose test instrument, range 20 cps to 700 MC. Also serves as dc VTVM with over 100 megohms impedance, or ohmmeter for measurements 0.2 to 500 megohms. Input capacity 1.5 $\mu\mu$f, 10 megohms input impedance; employs radical diode probe which virtually eliminates circuit loading. Industry's most versatile precision voltmeter. $245.00.

Instrument	Primary Uses	Frequency Range	Voltage Range	Input Impedance	Price
-*hp*- 400AB	General purpose ac measurements	10 cps to 600 KC	0.003 to 300 v 11 ranges	10 megohms 25 $\mu\mu$f shunt	$200.00
-*hp*- 400D	Wide range ac measurements High sensitivity	10 cps to 4 MC	0.001 to 300 v 12 ranges	10 megohms 15 $\mu\mu$f shunt	225.00
-*hp*- 400H	High accuracy wide range ac measurements	10 cps to 4 MC	0.001 to 300 v 12 ranges	10 megohms 15 $\mu\mu$f shunt	325.00
-*hp*- 410B	Audio, rf, VHF measurements; dc voltages; resistances	dc; ac—20 cps to 700 MC	0.1 to 300 v 7 ranges	dc—122 megohms; ac—10 megohms/ 1.5 $\mu\mu$f	245.00

-hp- 400H Vacuum Tube Voltmeter

Need extreme accuracy of 1%? New -*hp*- 400H covers 10 cps to 4 MC, has 5" meter with mirror scale, measures voltages 0.1 mv to 300 v. 10 megohm resistance minimizes circuit loading, amplifier with 56 db feedback insures lasting stability. Direct reading in db or v. Extremely high quality throughout. $325.00.

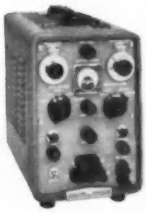
-hp- 400AB Vacuum Tube Voltmeter

Utmost utility, dependability, dollar value. Covers 10 cps to 600 KC, measures from 0.3 mv to 300 v. High stability, sensitivity, accuracy $\pm 2\%$ full scale from 20 cps to 100 KC. High input impedance; meter reads direct in volts and dbm. $200.00.

Instrument	Features	Price
-*hp*- 452A Capacitive Voltage Divider	For all -*hp*- ac VTVM. 25 cps to 20 MC. Division 1000:1	$100.00
-*hp*- 452-95A Adapter	Connects -*hp*- 452A to -*hp*- 410B VTVM probe	10.00
-*hp*- 453A Capacitive Voltage Divider	For -*hp*- 410B VTVM only. Division 100:1	25.00
-*hp*- 454A Capacitive Voltage Divider	For -*hp*- 400D and 400H only. Division 100:1	25.00
-*hp*- 459A DC Resistive Voltage Multiplier	For -*hp*- 410B VTVM. For measuring high dc voltages safely. Multiplies 1:100	25.00
-*hp*- 470A to F Shunt Resistors	For -*hp*- 400 series VTVM. For measurement of current.	470A - 15.00 470B-F - 7.50

-hp- Regulated and Klystron Power Supplies

-hp- 715A Power Supply



-*hp*- 715A is a versatile source of regulated beam and reflector voltage for operating most test bench klystron tubes. Beam voltage 250 to 400 v; reflector voltage 0 to 900 v; 6.3 v filament. Internal, 1,000 cps square wave modulation, and 60 cps sine wave modulation of reflector voltage. $300.00.

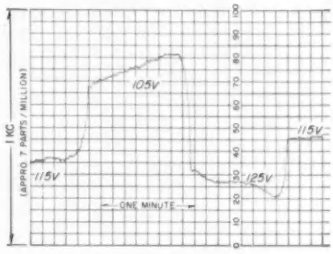
-hp- 712B Power Supply

This -*hp*- instrument features high regulation of 50 mv no load to full load, 0.1 millisecond transient response, internal impedance 0.1 ohms in series with 25 μH; full-load maximum hum less than 500 μv, sealed transformers, chokes and condensers. 0 to 500 v, 200 ma supply and fixed —300 v tap providing a 50 ma, 300 to 800 v variable supply for klystron operation. $365.00△.

Instrument	Primary Use	Characteristics	Price
-*hp*- 710B Power Supply	General Purpose regulated dc supply for lab and field use	100 to 360 volts @ 75 ma	$100.00
-*hp*- 711A Laboratory Power Supply	Same as 710B	0 to 500 volts @ 100 ma	225.00
-*hp*- 712B Power Supply	Same as 710B	0 to 500 volts @ 200 ma	365.00△
-*hp*- 715A Klystron Power Supply	Regulated beam, reflector source for low power klystrons	250 to 400 volts @ 50 ma	300.00
-*hp*- 717A Klystron Power Supply	Powering Type 5721 klystrons	800 to 1,000 volts @ 25 ma	375.00

△Rack mounted instrument available for $15.00 less.

New -hp- 560A Digital Recorder



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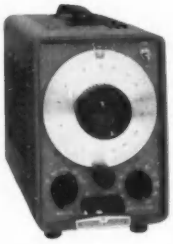
Revolutionary all-purpose counter measures frequency 10 cps to 1.1 MC, time interval 3 μsec to 27.8 hours, period 0.00001 cps to 10 KC. Stability 2/1,000,000 per week. Results displayed in sec, msec, μsec or KC; automatic decimal. Display time variable 0.1 sec to 5 sec or indefinitely. Accuracy ±1 count plus crystal stability, 5 gate times. Usable with 100 KC primary standard. $1,175.00.

Instrument	Primary Uses	Frequency Range	Characteristics	Price
-*hp*- 100D Secondary Standard	Frequency, time measurements	100 KC, 10 KC, 1 KC, 100 cps, 10 cps	Stability 1/1,000,000 (short-time). Sine or rectangular output. Marker pips	$ 615.00△
-*hp*- 335E TV Monitor	Aural and visual carrier monitoring; black and white or color	Channels 2 to 83	Aural deviation ±3 KC; video deviation ±3 KC; accuracy ±500 cps approx.	2,050.00
-*hp*- 500B Electronic Frequency Meter	Rapid frequency measurements	3 cps to 100 KC	9 ranges ±2% accuracy. Input 0.2 to 250 volts	285.00
-*hp*- 500C Electronic Tachometer Indicator	Rpm measurements	180 to 6,000,000 rpm	Similar to 500B but calibrated in rpm	285.00
-*hp*- 506A Optical Tachometer Pickup	Rps and rpm measurement	300 to 300,000 rpm	Phototube and light source; output 1 v rms	100.00
-*hp*- 508A Tachometer Generator	Shaft speed measurement	15 to 40,000 rpm	Output 60 cycles per revolution	100.00
-*hp*- 508B Tachometer Generator	Shaft speed measurement	15 to 40,000 rpm	Output 100 cycles per revolution	100.00
-*hp*- 508C Tachometer Generator	Shaft speed measurement	15 to 40,000 rpm	Output 120 cycles per revolution	100.00
-*hp*- 508D Tachometer Generator	Shaft speed measurement	15 to 5,000 rpm	Output 360 cycles per revolution	100.00
-*hp*- 520A Nuclear Scaler	For counting high-rate pulses	Capacity 100 counts in 2 decades. 10,000,000 pps counting rate	100:1 divider for operation of low speed scalers	615.00△
-*hp*- 521A Industrial Electronic Counter	Measure frequency, speed	1 cps to 120 KC	Direct reading, accurate within ±1 count ±0.1%, 4 place registration	475.00
-*hp*- 521C Industrial Electronic Counter	Measure frequency, speed	1 cps to 120 KC	Direct reading, accuracy within ±1 count ±0.01%, 5 place registration	650.00
-*hp*- 522B Electronic Counter	Frequency, period, time interval measurements	10 cps to 120 KC	Direct reading, accuracy ±1 count ±0.001%	915.00△
-*hp*-523B Electronic Counter	Frequency, period, time interval	10 cps to 1.1 MC	Direct reading, accuracy ±1 count ±2/1,000,000	1,175.00

△Rack mounted instrument available for $15.00 less.

-hp- Oscillators – 0.008 to 10,000,000 cps

-hp- 200 Series Audio Oscillators



For audio and ultrasonic measurements, *-hp-* offers popular Models 200AB and 200CD. Both have highest stability and accurate tuning circuits. Low impedance operating levels plus superior insulation guarantee long years of trouble-free dependability. Operation is simple; just three controls; no zero setting necessary. *-hp-* 200AB, 20 cps to 40 KC, $130.00. *-hp-* 200CD, 5 cps to 600 KC, $160.00.

Instrument	Primary Uses	Frequency Range	Output	Price
-hp- 200AB	Audio tests	20 cps to 40 KC	1 watt/24.5 v	$130.00
-hp- 200CD	Subsonic through supersonic audio and ultrasonic tests	5 cps to 600 KC	160 mw or 10 v/600 ohms; 20 v open circuit	160.00
-hp- 200J	Interpolation, frequency measurements	6 cps to 6 KC	160 mw/10 v	275.00
-hp- 202A	Low frequency measurements	0.008 to 1200 cps	28 mw or 30 v p-p/4000 ohms	465.00△
-hp- 202C	Servo equipment tests, measurements	1 cps to 100 KC	160 mw or 10 v/600 ohms	300.00
-hp- 207A	Audio sweep generation	20 cps to 20 KC	160 mw or 10 v/600 ohms	275.00
-hp- 650A	Wide range video tests	10 cps to 10 MC	15 mw/3 v	490.00△

△ Rack mounted instruments available at $15.00 less.

-hp- 207A Sweep Oscillator

This new audio oscillator provides continuous single-sweep frequency coverage from 20 cps to 20 KC. No band switching is needed; dial accuracy is 4%, and the instrument also provides a flexible 10 v/600 ohm output usable balanced or with one side grounded. Frequency response is ±1.0 db full range, distortion and hum are less than 1%. *-hp- 207A may be swept by hand, motor driven, tuned remotely or coupled to a recorder. -hp-* 207A, $275.00.

-hp- 202A Function Generator

Compact, multi-purpose source of transient-free test voltages from 0.008 cps to 1,200 cps. Continuously variable through 5 bands; offers exceptional stability (within 1%) and distortion less than 1% to 100 cps. Sine, square or triangular waves may be selected by a front panel switch; the 30 volt output peak-to-peak is constant for all wave forms and over full frequency range. *-hp-* 202A, $465.00.

-hp- 650A Test Oscillator

Covering 10 cps to 10 MC, *-hp-* 650A is a highly stable, wide band instrument for audio, supersonic, video and rf measurements. Output is flat within 1 db full range; voltage range is 0.00003 to 3 v. In addition to 600 ohm impedance, voltage divider provides a 6 ohm impedance. Distortion less than 1% to 100 KC; stability ±2% to 100 KC. $490.00.

-hp- Sales and Service Representatives in the United States and Canada

Albuquerque, New Mexico
Neely Enterprises
107 Washington St. S. E.
Albuquerque 5-5586

Asbury Park, New Jersey
I. E. Robinson Company
905 Main Street
KEllog 1-3150

Atlanta 5, Georgia
Bivins & Caldwell
3133 Maple Drive, N. E.
CEdar 3-7522

Baltimore, Maryland
Horman Associates, Inc.
635 St. Johns Road
HOpkins 7-2290

Bogota, New Jersey
R. M. C. Associates
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DIamond 3-5926

Boston Area
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Middlesex Turnpike
Burlington 7-2561

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1101 East Main Street
FOrest 6-3456

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I. E. Robinson Company
2120 Market Street
REgent 7-6791

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Crossley Associates, Inc.
2711 West Howard Street
SHeidrake 3-8500

Cleveland 21, Ohio
S. Sterling Company
4311 Mayfield Road
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FLeetwood 7-1881

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High Point 3672

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JAckson 4-9303

Kansas City 30, Missouri
Harris-Hanson Company
7916 Paseo Blvd.
HIlland 4-6744

Las Cruces, New Mexico
Neely Enterprises
126 S. Water Street
JAckson 6-2486

Los Angeles, California
Neely Enterprises
3939 Lankershim Blvd.
North Hollywood, Calif.
STanley 7-0721

New York 21, New York
R. M. C. Associates
236 East 75th Street
TRafalgar 9-2023

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7404 West Chester Pike
SHerwood 8-1294

Phoenix, Arizona
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641 East Missouri
CRestwood 4-5431

Pittsburgh 22, Pennsylvania
S. Sterling Company
Room 815, Park Bldg.
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Portland 9, Oregon
ARVA (formerly Ron Merritt Co.)
1238 N. W. Glisan
CApitol 7-1281

Sacramento 14, California
Neely Enterprises
1317 - 15th Street
GIlbert 2-8901

San Diego 6, California
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ACademy 3-8106

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San Carlos, California
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LYtell 1-2626

Seattle 99, Washington
ARVA (formerly Ron Merritt Co.)
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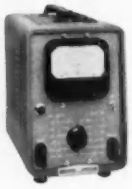
HEWLETT-PACKARD COMPANY

4408H PAGE MILL ROAD, PALO ALTO, CALIFORNIA, U. S. A.

CABLE "HEWPACK" DAvenport 5-4451

-hp- Vacuum Tube Voltmeters – 10 to 700,000,000 cps

-hp- 400D Vacuum Tube Voltmeter



Best *-hp-* voltmeter ever built! Covers all frequencies 10 cps to 4 MC. Extremely sensitive, wide range, accurate within 2% to 1 MC, measures 0.1 mv to 300 v. Direct reading in dbm. 10 megohm input impedance insures negligible loading on circuits under test. New amplifier circuit with mid-range feedback assures utmost stability, freedom from change due to external conditions. $225.00.

Instrument	Primary Uses	Frequency Range	Voltage Range	Input Impedance	Price
-hp- 400AB	General purpose ac measurements	10 cps to 600 KC	0.003 to 300 v 11 ranges	10 megohms 25 $\mu\mu$f shunt	$200.00
-hp- 400D	Wide range ac measurements High sensitivity	10 cps to 4 MC	0.001 to 300 v 12 ranges	10 megohms 15 $\mu\mu$f shunt	225.00
-hp- 400H	High accuracy wide range ac measurements	10 cps to 4 MC	0.001 to 300 v 12 ranges	10 megohms 15 $\mu\mu$f shunt	325.00
-hp- 410B	Audio, rf, VHF measurements; dc voltages; resistances	dc; ac—20 cps to 700 MC	0.1 to 300 v 7 ranges	dc—122 megohms; ac—10 megohms/ 1.5 $\mu\mu$f	245.00

-hp- 410B Vacuum Tube Voltmeter

All-purpose test instrument, range 20 cps to 700 MC. Also serves as dc VTVM with over 100 megohms impedance, or ohmmeter for measurements 0.2 to 500 megohms. Input capacity 1.5 $\mu\mu$f, 10 megohms input impedance; employs radical diode probe which virtually eliminates circuit loading. Industry's most versatile precision voltmeter. $245.00.

-hp- 400H Vacuum Tube Voltmeter

Need extreme accuracy of 1%? New *-hp-* 400H covers 10 cps to 4 MC, has 5" meter with mirror scale, measures voltages 0.1 mv to 300 v. 10 megohm resistance minimizes circuit loading, amplifier with 56 db feedback insures lasting stability. Direct reading in db or v. Extremely high quality throughout. $325.00.

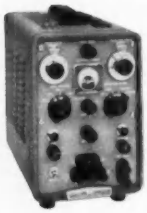
-hp- 400AB Vacuum Tube Voltmeter

Utmost utility, dependability, dollar value. Covers 10 cps to 600 KC, measures from 0.3 mv to 300 v. High stability, sensitivity, accuracy ±2% full scale from 20 cps to 100 KC. High input impedance; meter reads direct in volts and dbm. $200.00.

Instrument	Features	Price
-hp- 452A Capacitive Voltage Divider	For all *-hp-* ac VTVM. 25 cps to 20 MC. Division 1000:1	$100.00
-hp- 452-95A Adapter	Connects *-hp-* 452A to *-hp-* 410B VTVM probe	10.00
-hp- 453A Capacitive Voltage Divider	For *-hp-* 410B VTVM only. Division 100:1	25.00
-hp- 454A Capacitive Voltage Divider	For *-hp-* 400D and 400H only. Division 100:1	25.00
-hp- 459A DC Resistive Voltage Multiplier	For *-hp-* 410B VTVM. For measuring high dc voltages safely. Multiplies 1:100	25.00
-hp- 470A to F Shunt Resistors	For *-hp-* 400 series VTVM. For measurement of current.	470A - 15.00 470B-F - 7.50

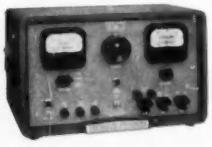
-hp- Regulated and Klystron Power Supplies

-hp- 715A Power Supply



-hp- 715A is a versatile source of regulated beam and reflector voltage for operating most test bench klystron tubes. Beam voltage 250 to 400 v; reflector voltage 0 to 900 v; 6.3 v filament. Internal, 1,000 cps square wave modulation, and 60 cps sine wave modulation of reflector voltage. $300.00.

-hp- 712B Power Supply



This *-hp-* instrument features high regulation of 50 mv no load to full load, 0.1 millisecond transient response, internal impedance 0.1 ohms in series with 25 μH; full-load maximum hum less than 500 μv, sealed transformers, chokes and condensers. 0 to 500 v, 200 ma supply and fixed —300 v tap providing a 50 ma, 300 to 800 v variable supply for klystron operation. $365.00△.

Instrument	Primary Use	Characteristics	Price
-hp- 710B Power Supply	General Purpose regulated dc supply for lab and field use	100 to 360 volts @ 75 ma	$100.00
-hp- 711A Laboratory Power Supply	Same as 710B	0 to 500 volts @ 100 ma	225.00
-hp- 712B Power Supply	Same as 710B	0 to 500 volts @ 200 ma	365.00△
-hp- 715A Klystron Power Supply	Regulated beam, reflector source for low power klystrons	250 to 400 volts @ 50 ma	300.00
-hp- 717A Klystron Power Supply	Powering Type 5721 klystrons	800 to 1,000 volts @ 25 ma	375.00

△Rack mounted instrument available for $15.00 less.

What's the Market for Computing-Control?

Ask any computer manufacturer *if* he thinks there's a market for computing-control and you'll get a resounding "yes" answer. But try to nail him down as to *how big* that market is, or will be, and you get almost as many answers as there are computer manufacturers.

CONTROL ENGINEERING asked 16 manufacturers, representing makers of analog and/or digital computers, what dollar volume the industry might expect from sales of computers for computing-control. Most were reluctant to predict exact figures yet. But from bits and pieces, CONTROL ENGINEERING was able to put together this estimate:

Dollar estimates

	Military Market (Millions)	Industrial Market (Millions)
1958.....	$50 to 200	$0.1 to 1.5
1960.....	200 to 500	5 to 25
1965.....	500 to 900	50 to 125

And market researchers estimate that the computer would make up from 15 to 50 percent of the cost of a control system!

Military sales

Right now the military market is the one with the most steam behind it. Even control experts at the Air Force's Air Research & Development Headquarters are unable to estimate how much will be spent for computing-control in the next few years. But Col. C. E. Evans, ARDC Chief of Bombing, Missile Guidance and Flight Control outlines a positive market when he says, "Digital computing-control is being designed into the next generation of military aircraft."

One supplier to the military interprets this statement to mean that sales of computers for airborne control will reach close to $500 million by 1960, subject, of course, to the usual ups and downs of military appropriations.

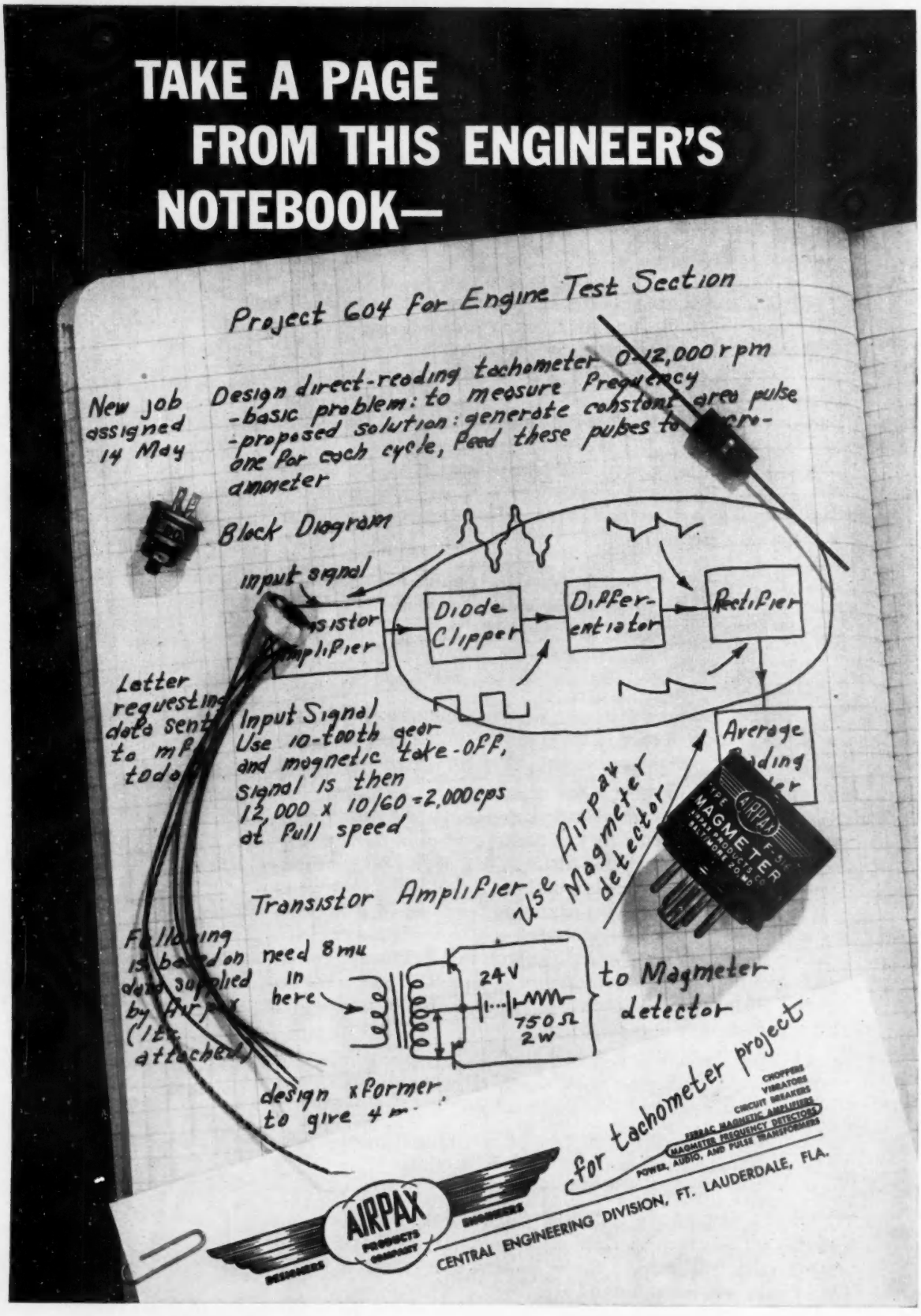
Industrial outlook

Outside the military field, suppliers believe computing-control will be accepted more slowly. They agree that these industries offer the best potential markets:

1. Petroleum processing
2. Chemical processing
3. Utility industry
4. Testing
5. Machine tool and metalworking

The outlook for the industrial market in computing-control shapes up like this: the first important sale will be made in 1958; sales will increase slowly, finally taking hold in 1960; then, sales will zoom upward rapidly.

TAKE A PAGE FROM THIS ENGINEER'S NOTEBOOK—



There's a feeling among those who have studied the problem closely that the market potential for computers used in computing-control could surpass that for business and scientific data processing machines in 10 to 15 years (particularly when you add in the airborne control business). One other prediction that's being expressed often: today's big names in data processing computers will probably not hold the market for computers in process control.

New faces expected

Industry observers believe that companies who are more closely associated with studies in manufacturing process control will be able to capitalize on that background. The pundits predict a battle for computer sales involving a flock of new faces. Among the newcomers frequently mentioned: Daystrom Systems, GE's new computer department, Beckman Instruments and Ramo-Wooldridge (which launched an assault in the field).

Optimistic view

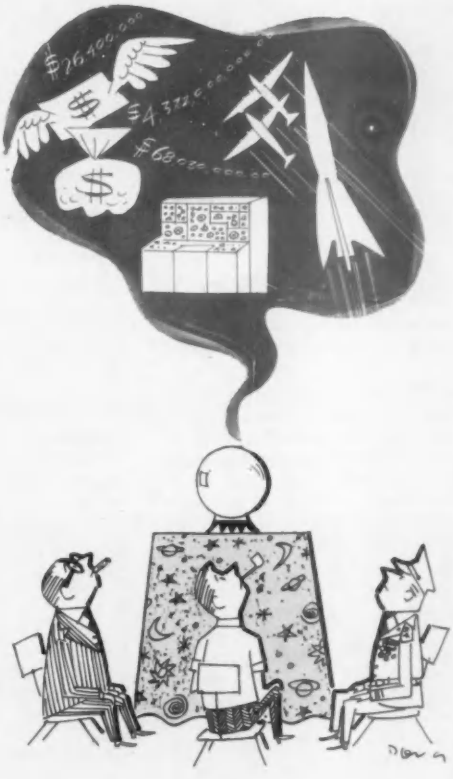
One company that's optimistic about industrial applications of computing-control is fast-growing Beckman Instruments. Beckman officials predict relatively quick acceptance in the chemical and petroleum processing fields and in heavily-instrumented test facilities. By 1960, they estimate that the computing-control equipment market (not counting computers) will total $50 million.

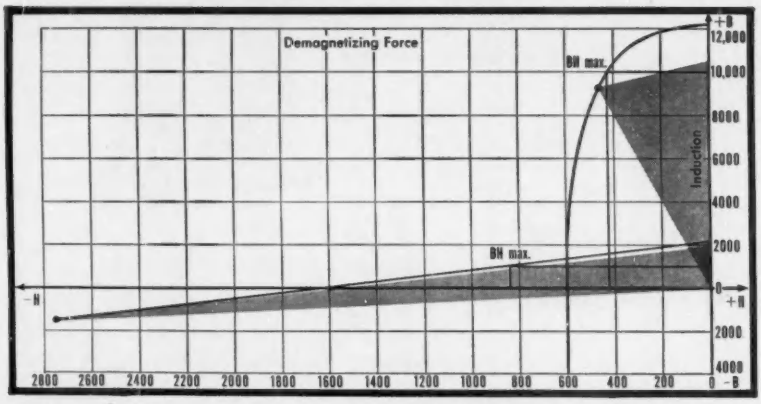
Supporters of this view cite the way automatic data loggers have caught on; they point to the development of new mathematical techniques, more reliable stream analyzers, and steady pressure from rising costs, which, they say, will hurry users into computing-control.

Another company that's betting on a big future in computing-control is Bendix Aviation Corp. Bendix's Computer Div. has already sold equipment for computing-control applications in wind-tunnels; chemical processing is next, the company says. It thinks sales to the chemical industry may go as high as $75,000,000 in five years.

At GE's new Computer Div., there's optimism tempered with conservatism. Marketing people see several places where computing-control will win acceptance but they feel it will take time.

The survey of the industry turned up one other fact: computer makers are ready, and in most cases eager, to get into computing-control. It's the users who are holding back.





Composite of demagnetization curves showing that for Alnico V, upper, and Indox I, lower. Operation in the third quadrant is produced when a demagnetizing force, stronger than the magnet, forces flux in a direction opposite normal operation, providing negative magnetic induction. Indox magnetic flux returns to full value when this force is removed.

Why Ceramic Magnet Fields Are Now Practical for D.C. Motors

G. R. Hennig, Senior Design Engineer, The Indiana Steel Products Company, explains in this interview why Indox ceramic magnets are now practical for d.c. motors ranging from fractional to multiple horsepower.

Question: Why is the use of Alnico magnets limited to rather small motors, such as toy motors? Why are only some very special larger motors equipped with permanent magnet stators at the present time?

Answer: The price per unit of usable magnetic energy dictates the size limit. Alnico contains very expensive raw materials. For small magnets weighing a fraction of an ounce, this is not too significant. Labor cost, however, the other main factor in any calculation, is a sizeable item in small units. This is not true when larger Alnico magnets are required. With Indox the opposite is true. Its raw materials are cheaper than copper, and it appears that the larger the motor—within a certain limit—the more economically the material can be applied.

Question: How can Indox I, with only ⅕ the energy product (BH max), of Alnico V, be recommended for motor usage where a high field energy is required?

Answer: Maximum energy product is a good criterion of quality for static conditions, such as in the magnet systems of moving-coil instruments or loudspeakers. In motors, generators, and many other applications where the magnet is subject to strong demagnetizing forces, maximum energy product is not an important consideration. One must consider the incremental permeability, even in the third quadrant of the hysteresis loop. The result is, that under the most extreme conditions, Indox I has a maximum usable energy of 17.4 in.-lb. per pound while Alnico V has only 13.7 in.-lb. per pound. Under conditions as found in motors, the usable energy of Indox I is about ½ instead of ⅕ of the usable energy of Alnico V.

Question: How does Indox V compare with Indox I and Alnico V, and where does this material find application?

Answer: Indox V is the strongest ceramic magnet material available today. Per unit of volume it provides more usable energy in motors than Alnico V does. Flat pieces with at least 2 sq. in. area are preferable for production. This means that Indox V is suitable for motors with about 1/25 hp and more, and not for the tiny toy motors.

Question: What are the size limitations for Indox I and Indox V motors?

Answer: Indox I is suitable for motors from the smallest possible size to about ⅛ hp. Indox V can be applied in much larger motors, possibly in the range up to 10 hp, or higher. The same applies for generators.

Question: Can any d.c. motor be converted to a permanent magnet-field motor?

Answer: Yes, most motors can be converted with very little design change. Others may require a considerable change in structure and layout of the armature.

Question: Is there a problem of meeting air gap tolerances with Indox I ring or segment stators, unless bore grinding is applied?

Answer: No. Even though there is an as-sintered tolerance of ± 1.5%, an Indox magnet may be compared with an air-core solenoid, and variations of the air gap length have little influence on the usable flux. Only the O.D. should be ground which is an inexpensive operation on centerless grinders.

Question: How will a permanent magnet motor compare with shunt or series wound motors?

Answer: In general, a permanent magnet motor will have characteristics falling between shunt and series wound motors. Although it will not duplicate the entire speed torque curve for either, it can duplicate characteristics over a specified range.

Question: What are the specific advantages of substituting permanent magnets for wound fields in motors?

Answer: The advantages are: Higher efficiency, cooler operation, less use of critical material such as copper and, possibly, simplification and cost reduction.

Question: Is there a possibility of using Indox in a.c. motors?

Answer: Yes. In addition to various synchronous timer motors, d.c. motors with Indox magnets can be used with the new, efficient power-rectifiers (silicon or others). The advantages over normal d.c. motors are higher starting torque and better speed regulation.

Question: How is the speed controlled in permanent magnet motors?

Answer: Normally, by varying the armature voltage, but also by using a magnetic shunt, by moving the armature axially out of the permanent magnet field, by rotating the brushes, or by an auxiliary field winding.

Question: Can a permanent magnet stator compete with an equal electromagnetic stator in size or total volume?

Answer: Yes, with the materials we have today it can. There is only one exception: Where wound fields are operated with high, short-time overloads.

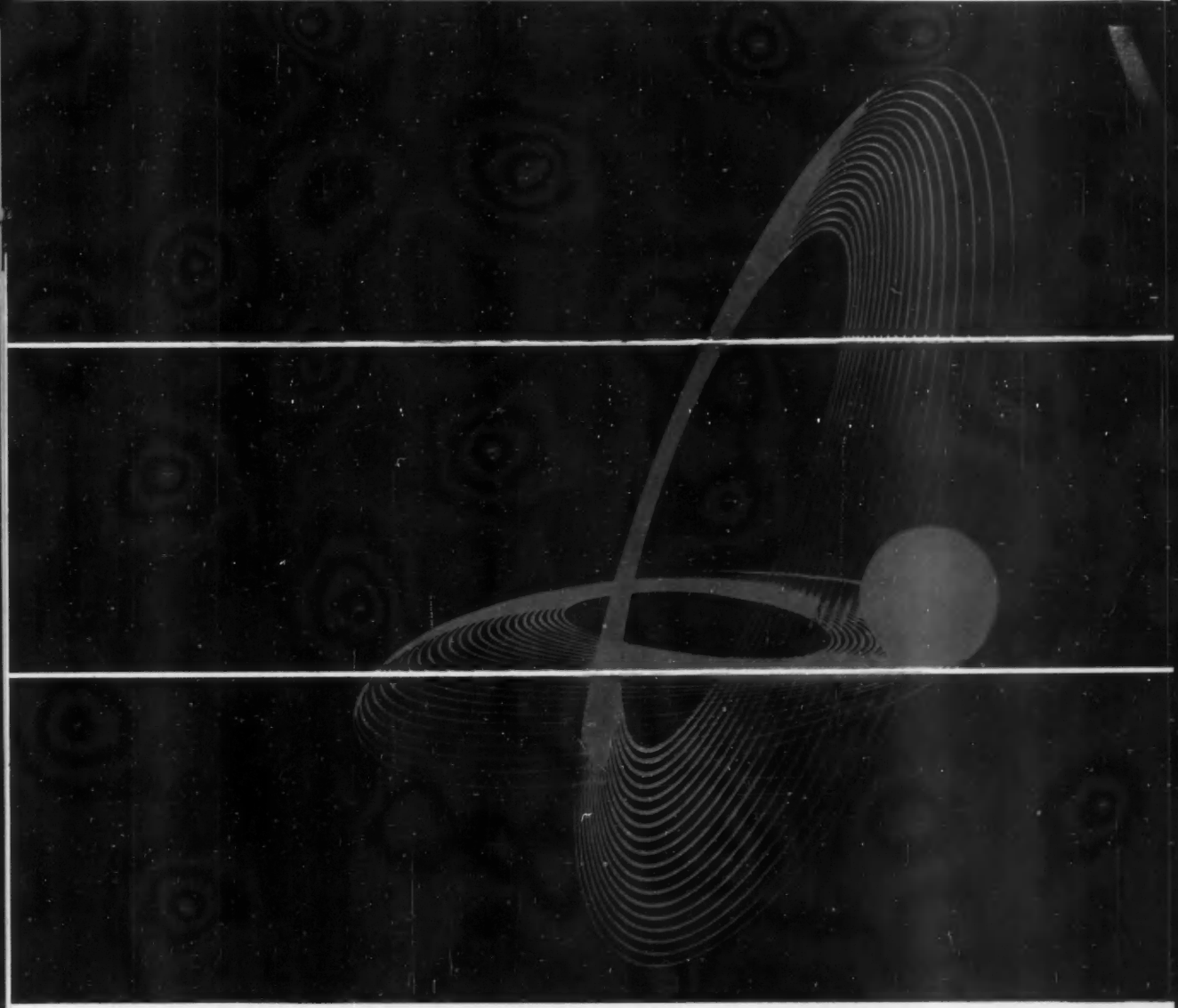
A complete reprint of Mr. Hennig's paper, "Applying Ceramic Permanent Magnets to Motor Design" appears in the July-September *Applied Magnetics*. Write today for your copy. Dept. P-10.

THE INDIANA STEEL PRODUCTS COMPANY
VALPARAISO, INDIANA

THE WORLD'S LARGEST MANUFACTURER OF PERMANENT MAGNETS

INDIANA PERMANENT MAGNETS

In Canada . . . The Indiana Steel Products Company of Canada Limited, Kitchener, Ontario



CONTROLONICS

THE SCIENCE OF CONTROL

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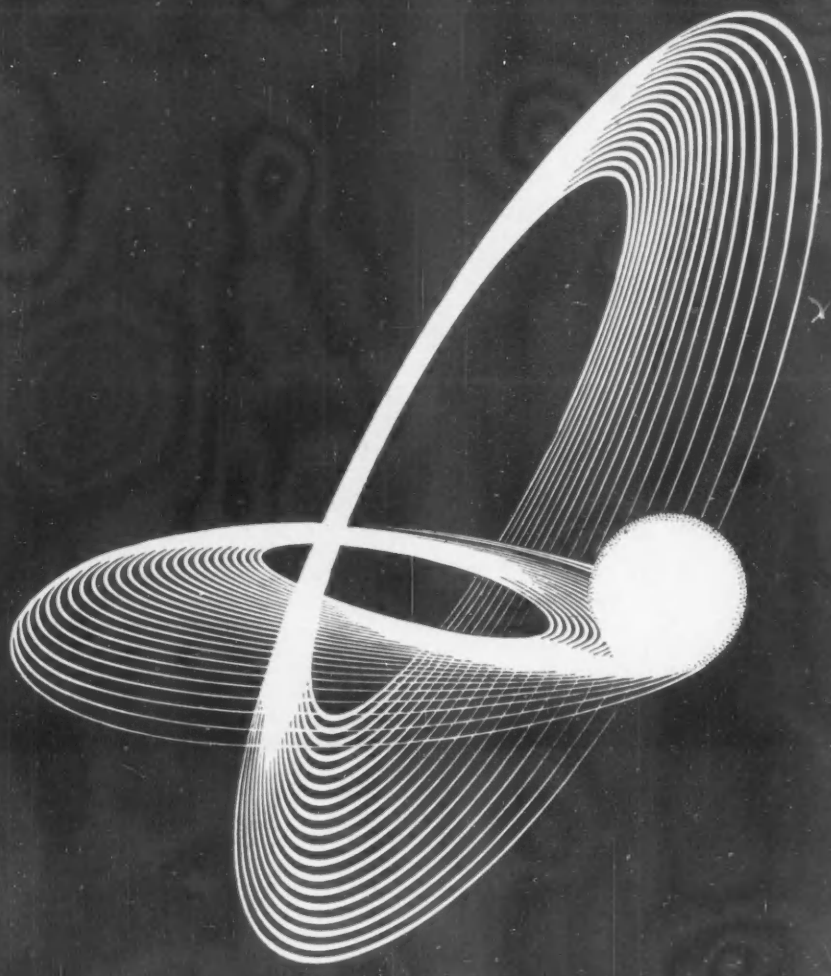
CONTROLONICS

The CONTROLON—a symbolic representation of CONTROLONICS.



CONTROLONICS—the science of control—is Daystrom's word for *measurement, computation, actuation.* Every day, through research, design, production—Daystrom continues to build a reputation as the source of products, service, and information in the field of CONTROLONICS.

Draw on the facilities and capabilities of the following Daystrom units. Whatever your CONTROLONIC requirement—there is a Daystrom unit to serve you.

THE SCIENCE OF CONTROL

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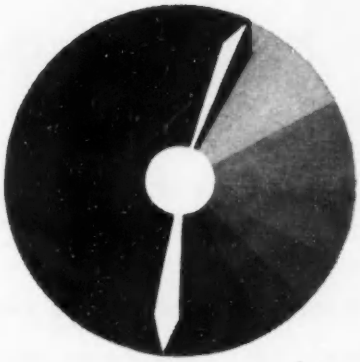
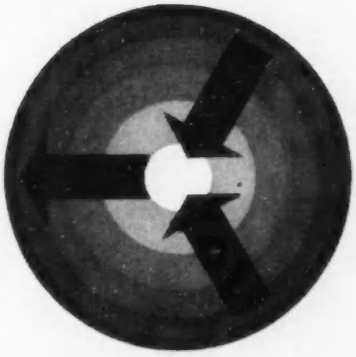
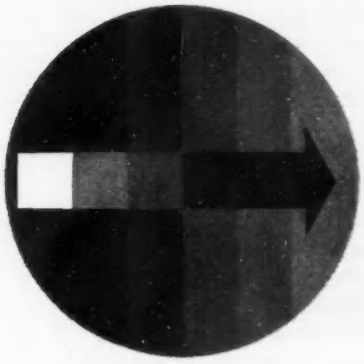


SERVO SYSTEMS

in measurement . . . computation . . . actuation





Weapons control . . . machine tool control . . . process control—a concise history of servomechanisms.

By spanning measurement, computation, and actuation, servos have become an essential ingredient in control, linking the analog output of controlled variables to analog or digital references for comparison and correction. And, in so closing the minor loops of control, they contribute to closure of the major optimum-seeking loop, the entire control system.

As a pioneer in servo technology, Daystrom Transicoil has made important contributions both to the development of the art, and its successful present day applications. For example:

SERVO SYSTEM CONTROLS AERIAL CAMERA FILM MOVEMENT
Servo assemblies compute correct film speed from flight variables to compensate for image movement during exposure period.

PINPOINT POSITIONING FOR SHIPS AT SEA
Servo system automatically compares phase relationship of three sets of fixed origin signals to determine location of receiver . . . fixes position to within a matter of feet.

AUTOMATIC POSITIONING SYSTEM FOR MACHINE TOOLS
Accepts signals from magnetic tape, punched tape, curve followers, to automatically perform numerous machining operations . . . jig-boring, hole layout, spot facing, boring, milling, and turning.

CONTROLLING AND INTEGRATING MANUFACTURING OPERATIONS
Servo systems control raw material feed rates to maintain desired overall production levels. Smooths out production peaks and valleys.

MEASURING, COMPUTING, AND ACTUATING IN PROCESS CONTROL
Servo systems tap the analogs of the process for direct analog computation and control, or for conversion into digital form for manipulation and control, and in some instances back to analog for servo correction.

Complete information on servo engineering services, servo systems, and servo components is available. Write for pertinent engineering bulletins covering Daystrom Transicoil standard servo components.

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DAYSTROM

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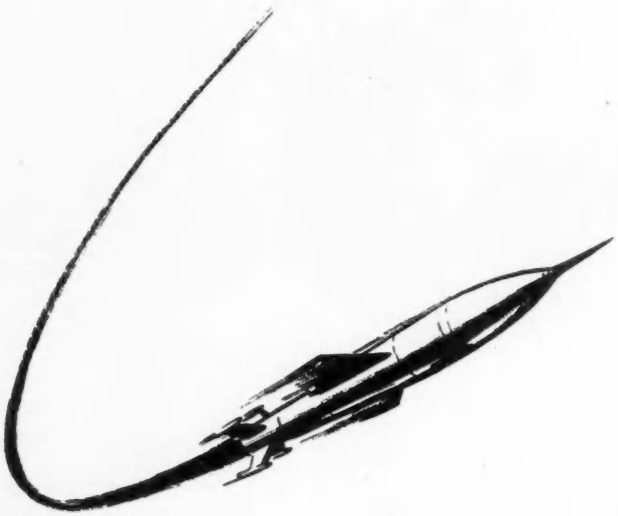

PRECISION COMPONENTS MEAN PRECISE CONTROL

American Gyro Division of Daystrom Pacific Corporation supplies precision control instruments for many of the finest missile control systems in existence.

American Gyro Division of Daystrom Pacific Corporation, backed by the tremendous resources of the Daystrom family, produces a group of miniature and sub-miniature control instruments that is far ahead of anything else in the field. When "feather-weight" and sub-miniature size are necessary without sacrifice of accuracy and ruggedness, American Gyro components supply the answer.

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SMALL IN SIZE, LIGHT IN WEIGHT, PRECISE IN ACTION
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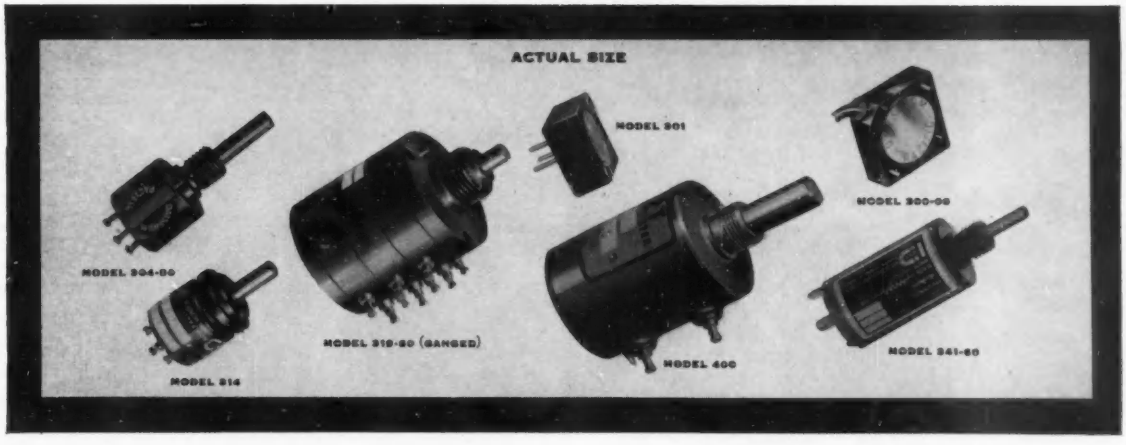
The engineers and production personnel at the Potentiometer Division of Daystrom Pacific combine to make an unbeatable team when used to solve your potentiometer problems.

WRITE TODAY for complete information.

SMALL IN SIZE, LIGHT IN WEIGHT, PRECISE IN ACTION

A FEW OF THE MANY POTENTIOMETERS BUILT BY DAYSTROM PACIFIC



CONTROLONICS

DAYSTROM SYSTEMS DIVISION

Offers Single Responsibility for the Design, Assembly, Testing, and Installation of Automatic Control and Operational Information Systems.

CONTROLONICS — Daystrom's word for the science of control—is a full-fledged branch of today's rapidly advancing technology. Its effective implementation calls for a pool of specialist engineers, scientists, and administrators from which can be drawn the knowledge and experience required to solve the complex and infinitely varying automatic control problems faced by industry, the military, and science.

Far-sighted management will recognize the advantage of being able to rely upon a single, qualified organization to design, develop, and produce the information and control systems it needs.

Daystrom Systems Division fulfills this need. Its engineers enjoy complete technical independence and freedom to seek and employ the best engineering practices in designing, constructing and assembling interrelated groups of mutually compatible devices into efficiently performing units and systems.

The primary concern of this group is uncompromising reliability. Daystrom Systems is organized to build each system from the most suitable components available and to develop special components when available equipment does not meet Daystrom design requirements.

The Automatic Control and Operational Information System

Controlonics—embracing *measurement, computation, actuation*—is exemplified in the Daystrom-designed Automatic Control and Operational Information System. A distinctive feature of this system is a specially designed digital computer constructed entirely with "solid state" elements. This eliminates completely the use of hot vacuum tubes, the least reliable elements in most digital computers. There are no filaments to burn out, envelopes to leak or fragile elements to short out. The programming flexibility of this computer is unlimited. Pinboards and patchboards—the usual programming accessories—are entirely eliminated. Programming is accomplished by punching paper tape with all the necessary instructions such as scanning sequence, sampling schedules, linearizations, scaling factors, range suppressions, alarm levels and conditions, temperature and pressure valves for flow compensation and computation instructions. Such information is fed into the computer where it is stored magnetically. The instructions, therefore, can be varied at any time without making any physical changes to the equipment. All analog voltages are converted to the digital form before any operations whatever are performed upon them. By digitizing the input voltages immediately, and not operating upon them in the analog form, inaccuracies introduced by analog computations are completely avoided.

The Daystrom Automatic Control and Operational Information System is designed to provide operators with ad-

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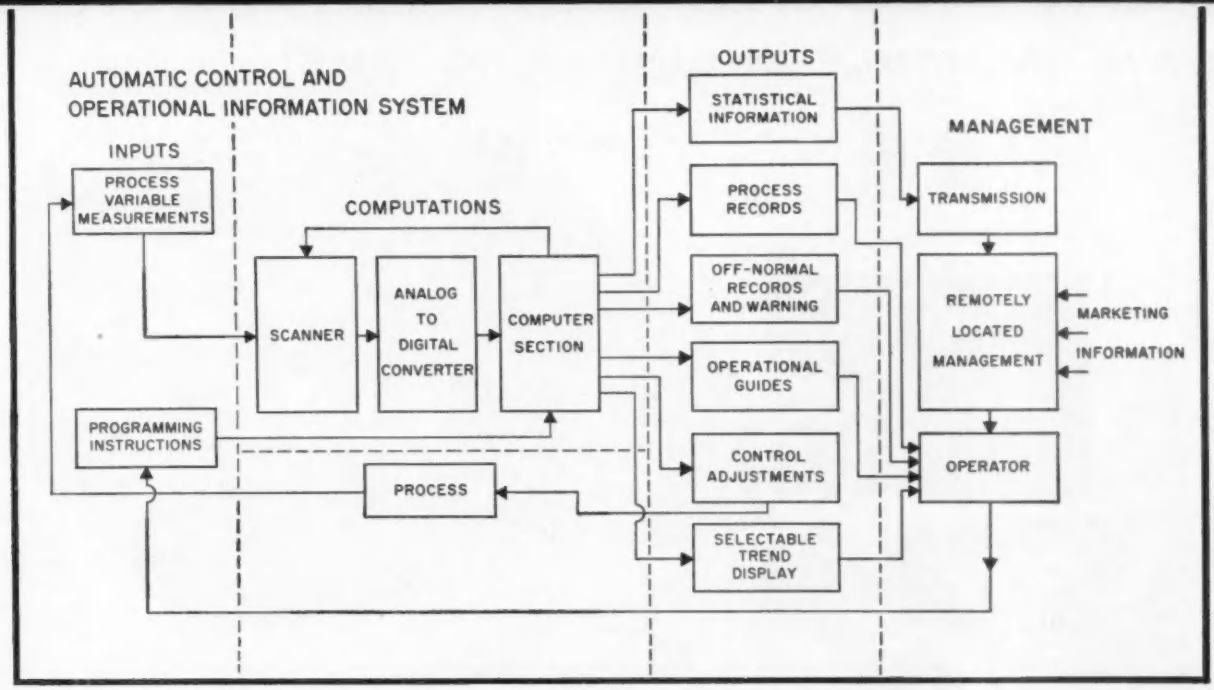

vanced types of information relating to plant operating efficiency, as well as to produce corrective signals to control equipment.

Progressive industrial management is investing in conventional data-logging systems primarily in the interests of gaining experience in the rapidly developing science of advanced control and operational information techniques. This has already led, in scattered cases, to minor loop computer control. The design of the Daystrom Automatic Control and Operational Information System capitalizes upon the accumulation of experience gained and now, in a single versatile system, takes the boldest step yet toward industry's ultimate goal of "closing the overall process loop."

Automatic Control—A Sound Investment

Daystrom Automatic Control and Operational Information Systems constitute a sound capital investment in such fields as chemical and petroleum processing, food processing, power generation and distribution, steel manufacturing and similar industrial activities. By reducing manpower, fully utilizing equipment, and maintaining product uniformity and quality unattainable by human control, automatic control systems justify their cost in wider operating profit margins.

The Systems Division, through its access to all Daystrom research and production facilities, can assemble systems more efficiently and at favorable cost to the customer.

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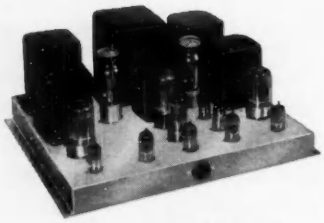
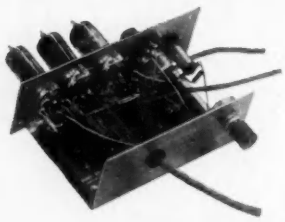


ES-2 AMPLIFIER POWER SUPPLY
A highly stable unit featuring voltage regulation and liberal component ratings.



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This advanced "slide rule" is a highly accurate device that permits engineering or research personnel to simulate equations or physical problems electronically, and save many hours of involved calculation.

Ideal for industry, research, or instructional demonstrations. Incorporates such features as:

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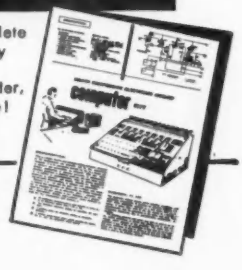

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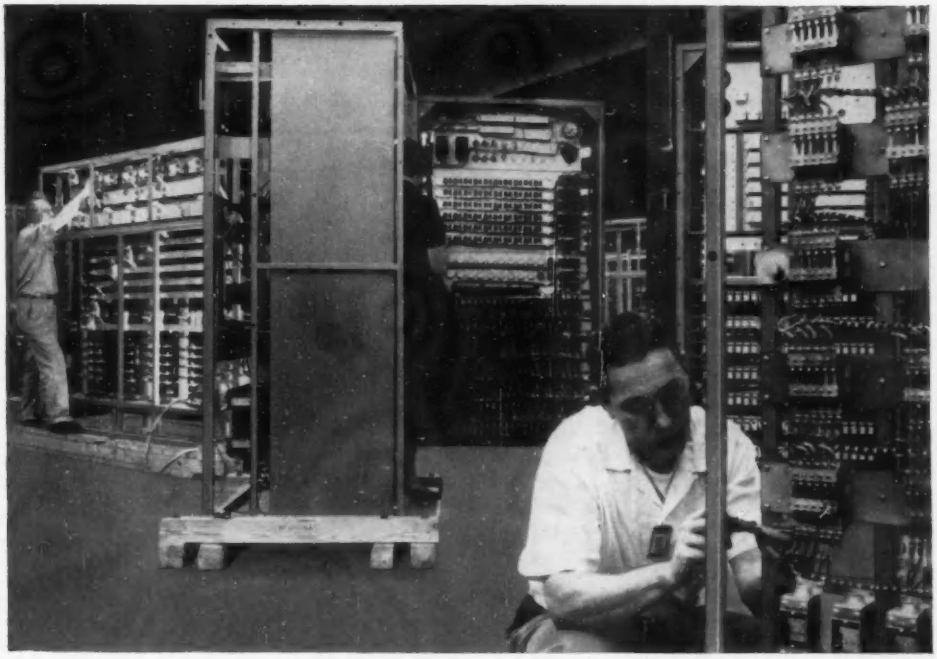
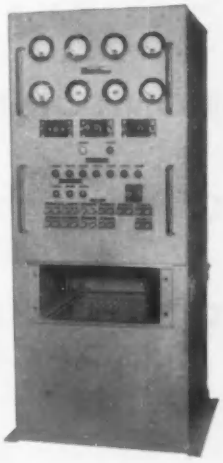
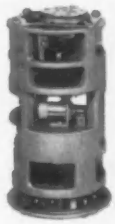
Daystrom Instrument will develop and manufacture control equipment and systems to meet your exacting needs. Through the years we've proven the RELIABILITY of our products to every branch of the Armed Forces . . . and to many of America's greatest industries. The talent, technical skills and facilities we make available to you assure a product which will meet your most critical requirements. And this goes for the development and manufacture of a complete system . . . or our entry "any place along the line."





RADAR SET CONTROL



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Power Control Distribution for SAGE

Other products made at Daystrom Instrument include fire control systems, communications systems, test equipment, attack directors, underwater ordnance, power supplies, electronic chassis, radar, gear assemblies, servo applications, aircraft instrumentation and many other electronic and electro-mechanical products.

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For control at the "turning point," Weston supplies a complete line of compact a-c and d-c current generators, in all mounting forms, and including types for hazardous locations. Also the new "bearingless" type, so small it can be built into original equipment, and used for speeds up to 100,000 RPM. Indicators are available calibrated in RPM, gals. per minute, feet per hour, or any other function of RPM.

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MECHANICAL CONTROLLERS

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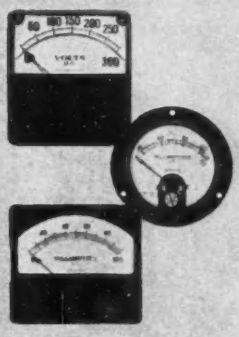
DAYSTROM INCORPORATED

PANEL INSTRUMENTS



The most comprehensive line of panel instruments available for monitoring and other requirements—round, rectangular and fan shapes—sizes from 1½" to 6"—as a-c, d-c, rf, thermo and rectifier types. Models available in ruggedized forms; also models with Cormag® self-shielding core magnet mechanism.

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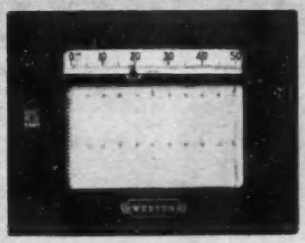
Full 10½" strip chart size potentiometer recorder in compact case (same size as single point recorders) which fit standard radio racks. Includes all the *unitized* design features of Weston instruments. Model shown available up to 12 points . . . other models up to 24 points, also single point recorder models.



SENSITIVE RELAYS

Weston supplies a complete line of high sensitivity relays, including the sealed Sensitrol® types. These miniature units operate direct on input signals as low as 1 millivolt or ½ microampere and their positive magnetic contacts handle substantial wattage at 110 volts. Available with single or double contacts, fixed or adjustable, manual or solenoid reset.

stability heretofore unknown!

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Virtually zero temperature coefficient • noise free • excellent high frequency characteristics • absolutely stable at low temperatures, in shock or under vibration • shelf life drift only a fraction of a percent per year • will not open under overload conditions • only .02% change in moisture tests • will change less than .5% in 1000 hour load life test at 125C. *More stable than precision wire-wound resistors, yet lower in cost! Surpasses tightest MIL specifications!*

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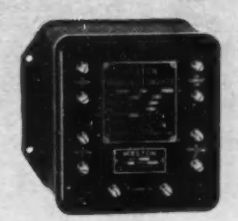

Weston supplies transducers which provide proportionate d-c signals for speed, light, heat and electrical quantities in terms of volts, amperes, watts, including:

THERMAL CONVERTERS, for remote measurement, totalizing, recording and control.

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Using the NMR Analyzer is remarkably swift and simple. The sample of material, enclosed "as is" in a sealed bottle, is placed in the test chamber and the scanning current switched on. The actual measurement is entirely automatic—the recording of the moisture content is inscribed on the moving chart that forms a permanent record.

The Schlumberger Analyzer is virtually foolproof after being set up. Tests are made simply by placing the sample in the testing receptacle and snapping on the scan switch. Thirty seconds is the normal recording time, although in some instances longer periods are required —never exceeding four minutes.

Its effectiveness has been proved through field use on materials such as starch, paper pulp, grain, candies, syrups, cotton, etc.

If you would like to learn how the NMR Analyzer will perform on *your* materials, we will be glad to run NMR tests on your samples. Please write for information on the preparation and packing of your samples. For technical data on the NMR Analyzer, address *Applications Group, Room 400, Schlumberger Well Surveying Corporation, Ridgefield, Connecticut.*

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Come to Booth 211 at the ISA Convention and see the new, spectacular NMR Analyzer read off moisture content of samples in just a fraction of a minute.

NMR Specialists will be in attendance to explain this new, nondestructive analysis and answer your questions.

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COMPUTING-CONTROL . . . has one over-riding justification—improved performance. It will bring about better performance of machinery, plants, and weapons, in terms of better stability of operation, quality of product, production rate, efficiency, or yield.

. . . uses these basic computing functions—addition-subtraction, multiplication-division, integration-differentiation, counting, and memory. Through them it combines and compares the interacting conditions and behavior of the equipment to which it is applied, and from these combinations and comparisons, it makes optimum changes in energy and material supplies or in subsystem commands.

. . . is the center of a widening circle of control techniques and products. Further advances require—

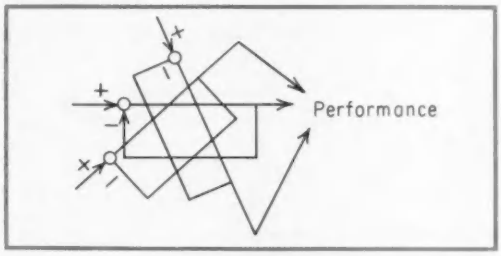
• analysis, to determine dynamic and static relationships which the computing controller must know

• invention, of instruments for direct measurement of performance where inferential measurements and computations prove inadequate.

By WILLIAM E VANNAH, Control Engineering

Computing-control joins computing functions and control functions. The usual fixed-function industrial regulator or military servo uses computing functions in elementary combinations. For instance, it determines error by subtracting the measured condition of a controlled variable from its desired condition. It integrates, differentiates, or somehow weights-in-time, the error to correct the rate at which energy or material is delivered to the controlled object. If the controller is a regulator, its immediate objective is to stabilize the controlled variable by automatically balancing varying loads. If a servo, it is to meet command changes accurately and quickly.

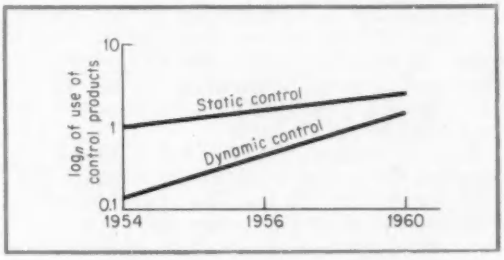
A look beyond the single loop controlling temperature, angle of attack, or power shows regulators and servos losing their individual characters and blending their objectives into one, the maintenance of performance. Multiple single control loops, each so applied that it ignores the effects of the others as much as possible, act to sustain the performance of complex weapons and production systems. In effect, they hold performance to within those tolerances that were determined when the separately controlled variables and their respective static setpoints were selected. The practice is widespread; it works well. Recent literature terms it "static" control because the control system does not dynamically adjust the desired conditions of each independent loop. The feature articles and the feature news stories in this issue address themselves, for the most part, to "dynamic" control, embracing systems which either dynamically adjust the separate desired conditions or incorporate all control functions in one integrated computing-control system.



Workhorse trims for the race

No one knows to what extent "dynamic" control systems will take over. They *will* increase in importance relative to static control loops, but the static control loop will at least hold its own. Several factors support this prediction. First, the static control loop is a proven workhorse. Second, many applications will not economically or technically justify "dynamic" control. Third, most of an expected 40-percent increase in the use of automatic control between now and 1961 will have to be met by control products designed for static control—because this we know how to manufacture and apply, while we still have much to learn about "dynamic" control. Fourth, the static control loop will take on some of the computing functions required for optimum control.

Recognizing the continuing importance of static control, manufacturers and independent researchers have pursued the development of two types of ad-



vanced single-loop control systems—multiple-regime controllers and self-adaptive controllers.

The multiple-regime controller, sensing a sustained change in load or command, applies maximum correction for an optimum interval and minimum correction for a subsequent optimum interval. At the correct instant it then switches to standard modulating control action. In one version of this controller a rudimentary computer solves the equation below,

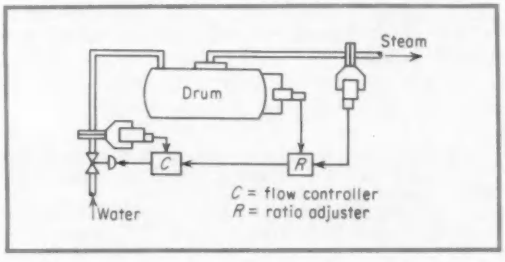
$$e + Ke'|e'|$$

introducing multiplication, to determine the correct time to return to modulating control. The equation solved by the computer includes coefficients which depend on the static and dynamic characteristics of the controlled system. Therefore the excellence of the multiple-regime controller's performance depends on the stability of the characteristics.

The self-adaptive controller, as its name implies, is supposed to alter its actions to fit the changing characteristics of the controlled system. Missiles and aircraft use a form of self-adaptive control in which an external variable directly adjusts gains and time-dependent control actions by amounts determined through analysis and test. The adjustment might be made by a measurement of altitude or air density, or, as in the case of the gain of the Lear Mk II commercial autopilot, by velocity of control surface movement. The objective is uniform control action—performance, to the pilot of a business plane.

Yesterday and today

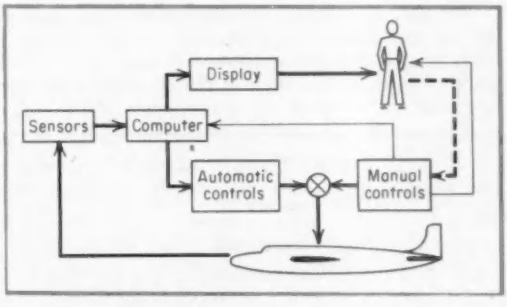
Like so many "new" techniques, computing-control is rooted in a past practice which has suddenly enlarged its scope. The expanding forces are economic need, stiffer technical requirements, and



control engineers with new equipment, creative ideas, and opportunities to follow them through. To rough in the dimensions of computing-control, we can start with the idea of one controlled variable automatically resetting the desired condition of another control loop to take care of the interaction between the measured variables of the two loops. Control engineers who developed turbo-jet-engine power controls recognized the interaction between engine temperature and speed and improved engine performance over wide ranges of operation by interconnecting temperature and speed measurement for the joint manipulation of fuel. For a long time, combustion controls have used three-element boiler drum-level control, a system in which the ratio of drum inflow to outflow is automatically adjusted by changes in drum level. These examples demonstrate the genesis of "dynamic" control. The "Computing-Control Applied" section illustrates current progress.

Centralized control, while not a dimension of computing-control, is an important influence on it. Any attempts to bring together data from the far corners of a process and convert the data to intelligence through coordinated control action sooner or later suggest prime opportunities for well-justified computing-control. The controller may be a machine or a man; today it is both. The dominant trend is toward taking the man out of the control system and putting him in parallel with it.

He thus becomes a highly intelligent monitor and planner, or tactician, whose millions of routine decisions are made by a computer. This is the prospect in the Belot, Cuba plant of Esso, where an analog computer will present the operator with guides for his decisions[a].



Each step, from the interconnected power control for the turbo-jet engine to the calculation of operator-manager displays and guides, has contributed its part to the technical evolution of computing-control. Each results in improved performance over wider ranges of operation.

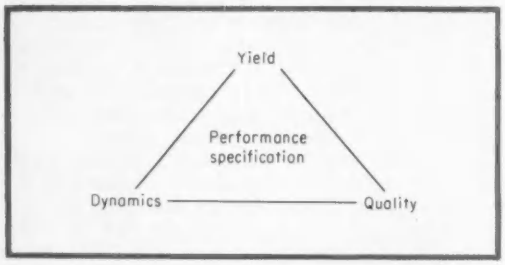
How to Do It

This issue follows the classic outline developed in the September '56 issue on control systems engineering. The steps laid out in that issue—specification, synthesis, and evaluation—are still the job routine. But for the engineering of computing-control systems they take on more scope because yield, productivity,

or operating cost become controlled variables.

The general goal, improved performance, requires a triangular specification.

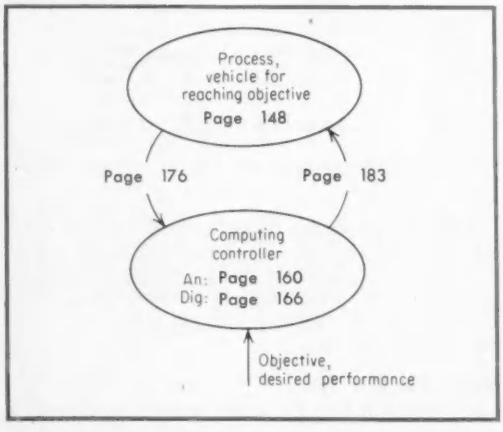
Management, whether of a weapons system or of an industrial process, must lay down specific objectives of improved weapon kill (yield), better productivity (also yield), or lower operating cost. Market research must set the quality requirements of the product. The control engineer must integrate these requirements into his specifications for dynamic performance.



Stating the three-way specification considerably magnifies the control engineer's job beyond detailed analysis of control and controlled equipment. Not only does he have to become completely familiar with the process to be controlled (as was demonstrated last September), but he also has to learn its weapon or business strategy. The five "Computing Control Applied" articles, pages 129 through 147 of this issue, and the two articles starting on pages 190 and 197 demonstrate the expansion of this job.

They, in company with the other features in the issue, also show the universality of the concept of "proceess", the vehicle for reaching the objective.

An editorial roadmap printed at the start of each of the next five articles illuminates in color that section of the computing control design route which each of them covers. Here is the complete roadmap.



Moving from the overall specifications prepared from a detailed study of the objectives and the process, the control engineer makes an intense examination of the interrelationships within the process to establish the "Control Problem for the Computer to "Solve". The article running from page 148 to page 159 with that title is a thorough treatment of ways to discover the interrelationships and what to do with them. The next four articles explain how to proceed around the loop.

Now the computing control loop is closed. We complete the issue with two unique examples, pages 190 through 204. The first, "Statistical Methods for Machine-Tool Gaging", is a description of an ingenious use of commercially available hardware. The second is an historic documentation of how a cooperative development project can probe the problems of industrial computing control.

Cross-correlations shape tomorrow's jobs

Though rooted solidly in past practice, computing-control is still new and has a lot of maturing to do. Because of its newness, much of the work reported by the experts who have authored articles in this issue is experimental. The experiments were independent of one another, and several were confidential. But despite this independence of effort, they reveal certain important common facets:

▶ The general justification is always improved performance, but the specific performance requirements, and therefore the justifications, vary with each job. Some of them stated are: better control of existing processes, only known way to control certain fast and absolutely unstable reactions, more satisfactory alarms and interlocks, optimizing of economics, and better-integrated data presentation.

▶ Approximate mathematical models suffice for the first round of iterative design and evaluation. The completion of projects still unreported will help to establish how faithful a mathematical model must be.

▶ Computing control is directing renewed attention to measurement and control hardware and to process design. An exquisite job of setting up a mathematical model and of designing an elegant data-processing and computing system can founder on inadequate measurement means and manipulating devices (valves, positioners, motors, energy exciters). Measurement, particularly, will receive more concentrated emphasis—by "users" and "manufacturer" alike.

Economic survival through more-automatic production and political survival through automatic weapons systems will continue to set the pace for control engineering developments. Both require the type of performance which flexible computing control can bring. This issue wraps in a minimum package the best thinking and techniques of computing control which we could gather in ten months of intensive search and selection. As improved applications and principles of computing control come to light, especially those which show large payouts in specific performance, we will publish articles and stories on them.

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2. *WILL THE LOGGER-COMPUTER OPTIMIZE REFINING "Control Engineering,"* March, 1957, pages 23-29.

Computing-Control Applied

Computing-control evolves from control-systems engineering. When the control engineer cannot find a satisfactory way to control his process by conventional techniques and equipment, a fresh look at his process often shows him a control or optimizing relationship requiring some sort of computation. He then reviews available control and computing equipment, and designs a unique controller. He has, in effect, developed a computing-controller. On the next 18 pages you'll find five descriptive and diversified case histories of the application of computing-control.

Cross-fertilization

The computing-control developments in one industry can have broad-scale influences on other industries. This cross-fertilization is important, for without it an engineer working on a computing-control problem may spend months and even years on a problem already solved by someone else.

For instance, there is the computer that locates the longitudinal position of a maximum temperature, described by Schuerger in his article (page 130) about the steel industry's sintering process. This computer can also be used for locating maximum temperature in chemical pipeline reactors to optimize reaction yields.

The nature of the control problem and the hoped-for results dictate the selection of the computing equipment. If the optimizing and control relationships are relatively uncomplicated and the process can be controlled in real time, then inexpensive equipment is adequate. This is the case for four of the applications on the following pages, all of which use analog components. But when the process requires repeated solutions of complex numerical relationships, like the fractionator (page 144), then a digital computer, tailored to the control job and perhaps time-shared with several other process units, seems called for even though it may be more expensive.

Cost as a factor

On some jobs a price of $2,000 or $3,000 for a computing-controller may be excessive, while on others several hundred thousand may not be too much to pay. The five examples that follow show no direct relationship between the cost of the computing-controller and the capital investment for the process equipment or the productive value of the process output.

Generally, however, there will be a rapid payout. For instance, Schuerger's computing-controller (which costs perhaps $4,000 or $5,000) when installed on a sintering machine normally rated at about 4,400 tons/day, can easily pay for itself in the significant increase in production.

The exception in the cost picture might be the airborne fire-controller (page 138). Here, extensive testing and investigation of ballistic requirements, complicated equations, and stringent environmental conditions raise the final cost. But in military applications low cost is not the justifying factor. The main consideration is human life.

Simple equipment often meets computing-control objectives. Lieberman proves this in a wind-tunnel application (page 134), which uses a combination of standard control hardware. Dornbusch shows that a leveling mill (page 141) can restore the taper to wrinkled aluminum sheets by using simple electronic operational amplifiers. Sometimes, too, more than one way exists for controlling the same process: the article on analog computing-control (page 160) discusses an alternative to compressor-surge control in a wind tunnel.

Computing-Control Applied to a

SINTERING PROCESS

Schuerger describes a low-cost system—a group of thermocouples and a modified standard potentiometer-indicator—that computes the position at which a sintering process reaches completion along the moving bed of the sintering machine. The computed signal controls the rate at which material is fed to the process to maintain it at its operator-selected production rate. Significant improvement in the 4,400-tons-per-day production of useful blast-furnace burden material is expected when this computing-control system is tied in with standard weigh feeders.

THOMAS R. SCHUERGER
United States Steel Corp.

In recent years the sintering process, which converts fine particles of iron ore into large particles, has become increasingly important to the steel industry. A mixture of fine iron ores and granular fuel is fed to a continuous grate where the mixture is ignited and burned in a downdraft combustion process. As a result, iron-ore fines, which normally blow through the blast furnace and reduce its yield, are changed into usable blast-furnace burden material.

Sintering process

Figure 1 is a simplified schematic of a sintering machine that actually has five to eight fine-ore storage bins, three to five additive storage bins, and one hot-recycle storage bin. The flow of material begins with feeding the fine-iron ore—previously screened from raw ore—onto the collector belt. Additives, which consist of coke fuel, flue dust from a blast furnace, and perhaps small quantities of other materials, are then delivered to the collector belt after the fine-ore. Finally, hot recycle, which is sintered ore that is too fine for use in the blast furnace, is added on top of the other materials. The resulting sinter mix then flows into the mixer, where water is added. Leaving the mixer, the wet sinter mix enters the feed end of the sintering machine. Here, the mix is spread to a depth of 12 to 14 in. on a continuously moving grate about 6 to 8 ft wide and 100 to 180 ft long.

The mix is ignited on its upper surface as it passes under the ignition furnace and the down-draft vacuum (or wind) system causes the mix to burn from its upper surface down to the grate surface as the grate moves forward. A large-capacity fan draws air down through the bed of the mix. The air passes through the bed into the windboxes underneath the entire length of the machine.

The sintered material discharges from the gate end onto a separating screen: oversize sinter is the desired sinter product, which is sent to the blast furnace; undersize sinter, called recycle or hot returns, is immediately sent to the recycle-storage bin. Recycled material is frequently a source of trouble in the sintering process. Its limited-capacity storage bin means that the recycled material must be used in new mix nearly as rapidly as it is received from the screen. If operation is unstable and large quantities of recycle are being obtained, the instability tends to regenerate through the recirculation of poor material in the recycle circuit.

Sintering is a physical and chemical process and should lend itself to close regulation by automatic means. All usable chemical processes have a region of stability that results in higher production and better product quality. A study of process variables leads to an understanding of how maximum process stability can be achieved.

Such a study for the sintering process is shown in Figure 2. The storage bins, the fan system, and the sintering machine (the physical plant) are shown in their proper relationship to the process independent variables: mix composition, mixing, bed permeability, and wind rate. Bed permeability is the sinter bed's resistance to air, or wind, flow through it. The constituents of the sinter mix should be homogeneously intermixed by the mixer, and the sinter mix should achieve the proper fluffiness so that the sinter bed is sufficiently permeable.

Interaction occurs among some of the variables. Mix composition influences mixing, mixing influences bed permeability, and bed permeability influences wind rate.

In older sintering plants the mixer and fan were designed into the plant as fixed-capacity nonadjustable devices so that process regulation normally consisted of manually controlling the composition and rate at which various constituents left the storage bins, and manually controlling grate speed to be compatible with sinter-mix burning rate.

Laboratory and field studies undertaken to improve the sintering process showed that:

- for a given grade of fine ore optimum ranges exist for percent fuel and for percent moisture in the sinter mix

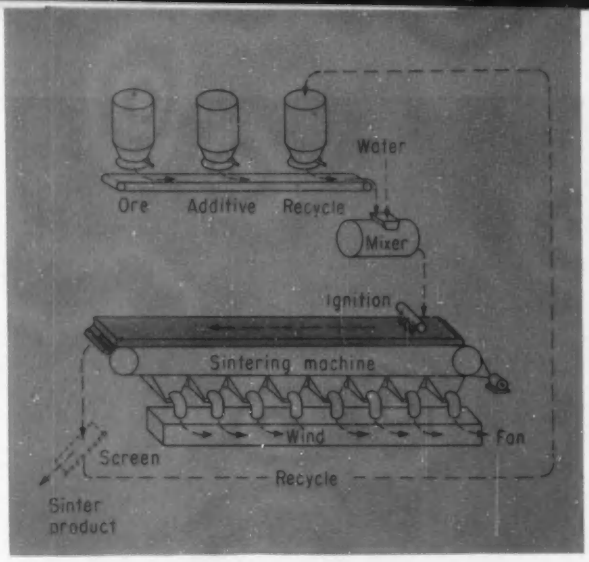


FIG. 1. Schematic of the Dwight-Lloyd sintering machine.

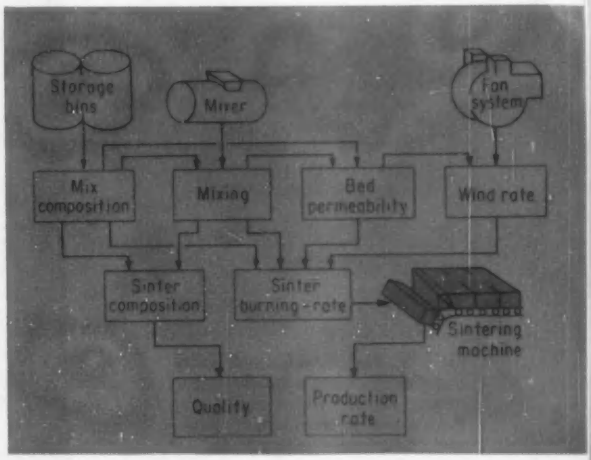


FIG. 2. This block diagram analysis shows the sintering-process physical plant, and the four independent variables that lead to two dependent variables, sinter composition (quality) and sinter burning rate (quantity).

▶ mixing and wind rate are important variables and this knowledge is now used when specifying mixer and fan capacities and design

▶ a simple relationship exists between the vertical burning rate of the sinter mix and the sinter-mix burn-through position on the moving grate. The burn-through position is the longitudinal position, on the continuously moving grate, at which the vertical burning zone reaches the grate. Maximum production results when burn-through occurs just prior to the discharge end of the machine.

Computing-controlled sintering

The study, in conjunction with Figure 2, indicates that the four independent variables lead to two primary dependent variables: sinter composition and sinter burning rate. However, sinter burning rate, which cannot be measured directly, is related to burn-through location and burn-through location is related to machine speed. Therefore, for a practical sintering process, two regulating factors are available:

▶ sinter-mix composition, which establishes sinter quality and which can be regulated from the storage bins

▶ sintering burning rate, which establishes production rate (and hence feed rate) and which can be regulated from sinter-machine speed

The operator need only set the percent of additives (water and coke) and the desired location of sinter-mix burn-through on the grate of the sintering machine.

The computing-control system (patents pending for part of it) contains two major control loops:

▶ the automatic speed-control loop—which measures bed level to adjust grate speed (production rate), computes burn-through position, and delivers a feed-rate signal to

▶ the automatic feed control loop —which proportions the constituents of the machine feed (quality control) and varies the feed rate in accordance with the signal from the speed loop.

Speed control

The automatic speed-control loop for the sintering machine is diagrammed in Figure 3. A level-sensor at the feed end of the sintering machine measures the amount of material arriving at the machine. If too much sinter mix arrives the sensor causes an increase in speed so that the machine uses all the material arriving. If too little arrives, machine speed is reduced so that the proper amount is always placed on the grate. Thus, grate speed is controlled as a function of feed rate.

The second important sensing element in the speed-control loop is a specially designed but simple detector for computing the sinter-mix burn-through location from wind - temperature measurements taken in the windboxes. Knowing burn-through location and machine speed permits calculation of the desired ore-plus-recycle feed rate reference signal that goes to the automatic feed-control loop.

Thus, with control loops linked, regulated sintering-machine speed

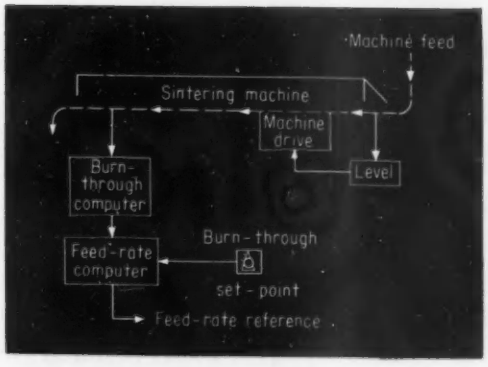


FIG. 3. The automatic speed-control loop uses a novel computer for finding the burn-through location of maximum temperature in the sinter bed.

FIG. 4. The average temperature in each windbox is measured. Near maximum temperature, the curve of temperature vs. windbox number can be approximated by a quadratic equation.

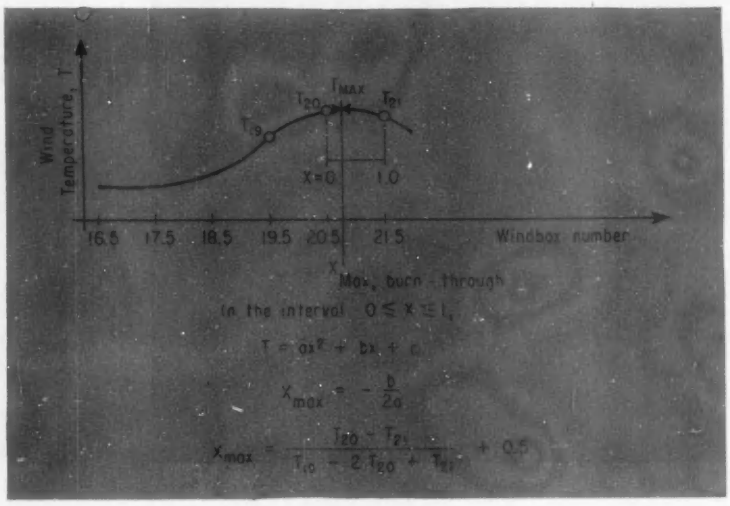
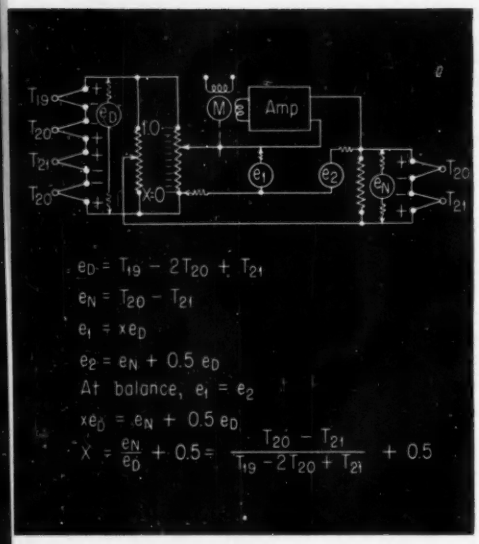


FIG. 5. The burn-through location can be found with this computing circuit, which solves for the location of maximum temperature of the curve in Figure 4.



always maintains the desired preset burn-through location.

Computing burn-through location

Burn-through indicates completion of the sintering process, and measurement of burn-through location is based on the curve shown in Figure 4. Wind temperature is plotted against 21 windboxes numbered from the feed end. The points 16.5, 17.5, etc., indicate the centers of their respective windboxes, and the temperature measured is the average temperature in each windbox. Wind temperature attains a maximum at the burn-through position, and the windbox-temperature curve in the vicinity of the burn-through location is such that the curve can be approximated by the quadratic equation.

$$T = ax^2 + bx + c$$

where x is defined within one windbox interval. To find the location of maximum temperature the quadratic is differentiated and set equal to zero:

$$x_{Tmax} = -b/2a$$

The location of maximum temperature is then a function of the coefficients of the original equation and these coefficients may be found by using standard difference techniques. Then:

$$x_{Tmax} = \frac{T_{20} - T_{21}}{T_{19} - 2T_{20} + T_{21}} + 0.5$$

This analog equation is developed by the circuit shown in Figure 5. Thermocouples measuring windbox temperatures are connected to this servomechanism and the burn-through location is generated as the position of a slidewire pointer. The burn-through computer thus converts discrete temperature information into a continuous indication of the location of the burn-through point along the grate of the sintering machine.

The denominator in the analog equation is developed by the group of four thermocouples: $T_{19} - 2T_{20} + T_{21}$. The numerator is developed by $T_{20} - T_{21}$. As shown in Figure 5, e_1 is equal to x times e_d, where e_d is the emf developed by the denominator thermocouples and x is the slidewire contactor position. Also, e_2 equals $e_n + 0.5e_d$, where e_n is the emf generated by the numerator thermocouples. The bias connection from the variable resistance in parallel with the slidewire fixes the $0.5e_d$ bias for e_2. The servo automatically seeks its null-balance position, and at balance e_1 equals e_2. Therefore, xe_d equals $e_n + 0.5e_d$, or:

$$x = e_n/e_d + 0.5$$

and by substitution:

$$x_{Tmax} = \frac{T_{20} - T_{21}}{T_{19} - 2T_{20} + T_{21}} + 0.5$$

The thermocouple inputs are easy to handle because they are essentially zero-impedance voltage sources. The arrangement shown is fully temperature-compensated in that all leads to the electrical portion of the measuring circuit are positive thermocouple wires. The circuit in Figure 5 measures an indicated burn-through location in any one given windbox. For control purposes the measuring range must be expanded over several windbox intervals. Then, several thermocouple groupings in different sets of windlegs are used in conjunction with tapped slidewires and cam switches. The United States Steel Applied Research Laboratory has constructed two computers that use automatic switching mechanisms to change sets of thermocouples when the burn-through location moves from one windbox range to another.

Figures 6 and 7 show the thermocouple well-assembly for one windbox and the front view of the most recently constructed Burn-Through Indicator.

Since the sintering machine is a fixed-capacity continuously-moving grate, machine speed is directly proportional to feed consumption. In other words, the speed of the sintering machine must be proportional to the feed rate and the machine speed calculated from the burn-through location is equivalent to the desired

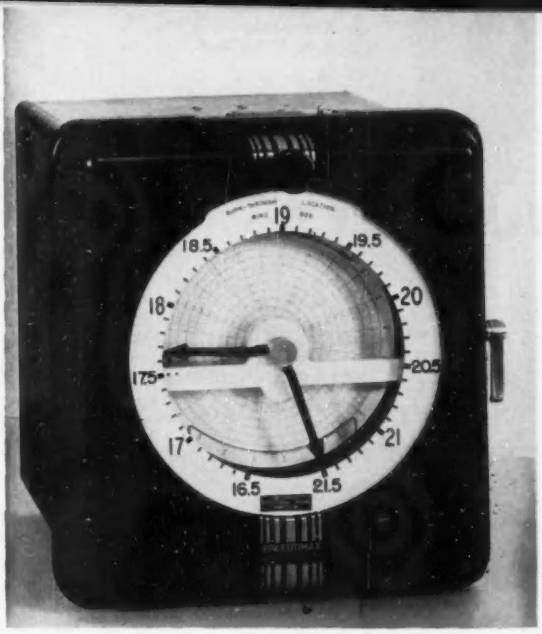


FIG. 7. The burn-through indicator computes the location of maximum temperature vs. windbox number and transmits this information for use in the feed-rate loop.

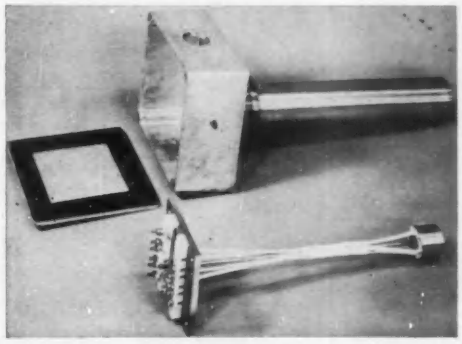


FIG. 6. Thermocouple and well-assembly for one windbox.

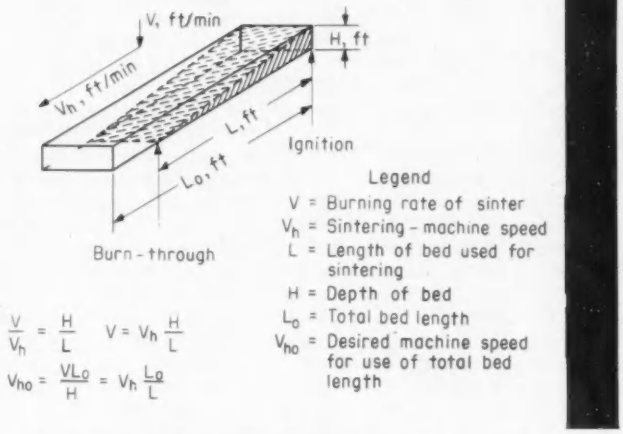

V, ft/min
H, ft
Vh, ft/min
L, ft
Ignition
Lo, ft
Burn-through
Legend
V = Burning rate of sinter
Vh = Sintering-machine speed
L = Length of bed used for sintering
H = Depth of bed
Lo = Total bed length
Vho = Desired machine speed for use of total bed length
V/Vh = H/L V = Vh H/L
Vho = VLo/H = Vh Lo/L

FIG. 8. Machine speed is simply related to burning rate.

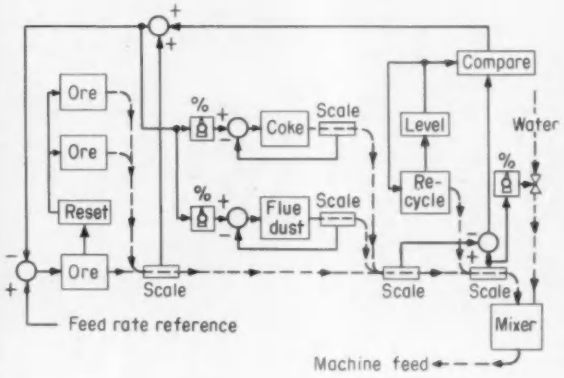


FIG. 9. The automatic feed-control loop uses commercially available weigh feeders to maintain preset proportions of ore, coke, and recycle. The feed-rate reference determines the tons/hr produced.

feed rate. The relationships in Figure 8 demonstrate that V_{ho} is the machine speed required to keep the burn-through position at L_o. Figure 8 also shows the ignition point on the sinter bed and a burn-through point. The unsintered material is the dark region on the lower side of the bed and the sintered material is the light region on the upper side of the bed.

The control-computer calculates machine speed V_{ho} and through a constant related to bed capacity it calculates the feed-rate reference required to maintain the desired burn-through location L_o. This computer is of the analog type, and performs its calculations intermittently because the feed rate is changed only at intervals equivalent to the transport time of a given element of sinter over the entire bed length. The burn-through signal is integrated over a small portion of the total sampling time to reduce the noise level of the measuring system.

Feed control

The automatic feed-control loop, Figure 9, receives the feed-rate signal computed in the speed-control loop. Individual scales weigh out ore, coke, and flue dust. Feed rate reference regulates ore-feed rate, and any deviation is automatically corrected through the feedback loop. The feed-rate reference at the ore bin is the total desired ore-plus-recycle feed rate. The feedback signal is the sum of the ore-feed rate as measured at the scale and of the recycle-feed rate from the recycle bin. A desired percentage of this feedback signal is selected on the dials by the operator and serves as the set-point for the feeding devices. The feedback-controlled weigh feeders automatically regulate the additive feed rates to the preset percentages.

The recycle feed rate depends only on recycle level in the limited capacity storage bin. The balance feed-rate reference signal is made up of ore. Additive feed rates are fixed percentages of the ore-plus-recycle reference, and these rates automatically follow the feed-rate demand from the computer.

Computing-Control Applied to

WIND TUNNELS

Lieberman picks three problems in continuous and blowdown wind tunnels that lend themselves to that area of computing-control handled by a controller and an assortment of common transducers and circuits: surge control to protect air compressors, correcting for variations in gain, and computing the density corrections for the compressed air.

DAVID A. LIEBERMAN*
Askania Regulator Co.

Wind-tunnel control is still another area that requires computational techniques, primarily because of the unusual relationships between the variables being controlled. Some ways that computing-control is applied here:

1. Determining the value of a variable not readily amenable to, or implicitly available for, measurement.
2. Correcting the system for loop-gain variations that might cause instability or sluggish operation.
3. Compensating for the effect of changing conditions on calibration.
4. Correcting the equation of state of a perfect gas for changes resulting from high pressures and temperatures.
5. Controlling nozzle opening for changes in Mach number.

Three specific examples of wind-tunnel control—surge control, gain compensation, and density correction—will be examined after a brief description of continuous and blowdown wind tunnels.

Wind tunnels

Because wind tunnels simulate aerodynamic and climatic conditions that may be encountered by an aircraft in flight, they permit a model of the aircraft (or a part of it) to be tested on the ground. The basic element of a wind tunnel is its nozzle, located upstream from a test chamber. Upstream from the nozzle is a stilling chamber. The model itself is in the test chamber. Nozzle shape and conditions in the stilling chamber determine the conditions of the air at the model. Therefore, stilling-chamber conditions must either be held constant during the test or follow a programmed set-point. For simplicity, it will be assumed that stilling-chamber pressure is the only controlled variable, although in practice the temperature would probably also be controlled.

Figure 1 is a schematic of a blowdown wind tunnel. Air is compressed to an extremely high pressure and stored in a large chamber. At time $t = 0$ a gate valve fully opens and allows the air to flow through a control valve to the stilling chamber and out through the nozzle. As the air in the storage chamber is exhausting, its pressure diminishes and the control valve must open wider to maintain desired conditions at the nozzle.

Figure 2 is a schematic of a continuous wind tunnel. A bank of compressors (represented here as one compressor) supplies the air. The compressors, in series-parallel to obtain necessary pressure and flow, are cascade-controlled. A base controller maintains nearly constant pressure at each compressor or compressor subgroup. A fine controller provides very accurate control of pressure at the stilling chamber by adding or subtracting small amounts of air.

Computing for surge controls

Surge control is a problem in continuous wind tunnels of preventing compressors, piping, and associated equipment from operating in an unstable surge region. The compressor series-parallel arrangement common to wind tunnels intensifies the surge problem.

At a given speed and temperature the compressor characteristics may be represented by a plot of its output-to-input pressure ratio vs. inlet volumetric flow. For a first approximation, speed may be assumed constant since the compressor will usually be driven by a synchronous motor, and inlet temperature may be assumed constant since interstage coolers will generally be used. Figure 3 shows two different compressor characteristics. Both curves show that over the compressor-operating range, pressure ratio decreases with increased flow through the compressor. Maximum volumetric flow occurs at a pressure ratio of unity, and as flow diminishes pressure ratio increases to some maximum value.

A surge point is indicated on each curve. Pressure ratios near or above the surge point cause the compressor system to become destructively unstable. Some form of relief valve (see Figure 2) is needed to blow off some of the outlet pressure and keep the system away from the surge region. However, because of the uniqueness of the control requirement, surge-point conditions are described by variables not readily available for direct measurement. The control problem divides into two main parts: 1) sensing an approach to surge conditions, and 2) preventing entry into the surge region.

If a compressor with a characteristic A is being controlled, then in the surge point region:

- pressure ratio is relatively constant
- inlet volumetric flow is a variable

Thus, measuring inlet volumetric flow indicates an approach to surge conditions. The method of making this measurement will be covered in a later section on density correction.

A compressor with characteristic *B*, on the other hand, exhibits these attributes:

* Mr. Lieberman is now with Applied Research, Inc., engineering consultants.

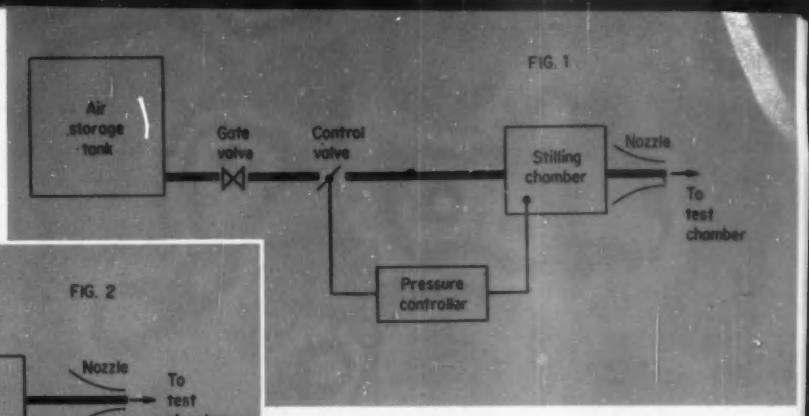


FIG. 1. Simplified schematic of a blowdown wind tunnel.

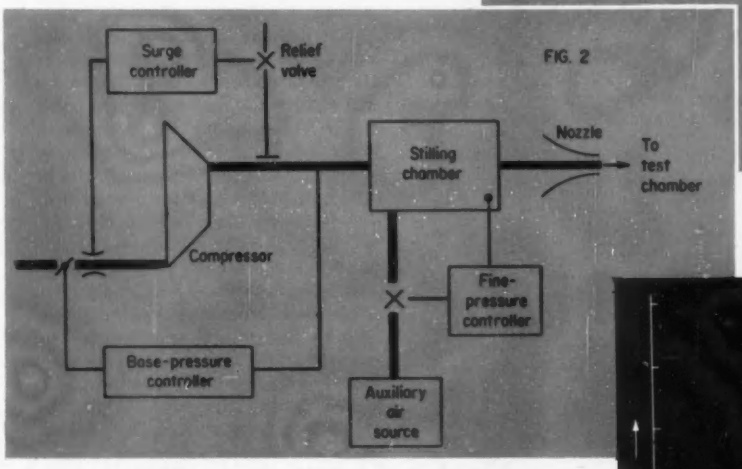


FIG. 2. Simplified schematic of a continuous wind tunnel.

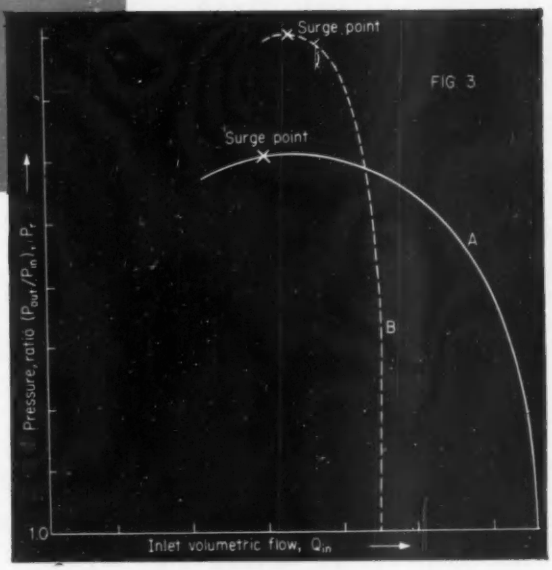


FIG. 3. Typical compressor characteristics indicating surge points.

▶ inlet volumetric flow is relatively constant

▶ pressure ratio is a variable

Since the slope of curve *B* is finite in the surge point region, it is tempting to use inlet volumetric flow again as a measure of approach to surge conditions—especially if a surge controller had been previously developed for characteristic A compressors. However, inaccuracies of available flow instruments may cause a large error in surge control.

Therefore, pressure ratio must be measured. Pressure transducers deliver voltages proportional to inlet and outlet pressure. But dividing one voltage by the other to get the ratio is not so easily done. Analog operational amplifiers may approximate the required division, but they could add complications. One practical way to get pressure ratio control is to use actual controller elements to perform the necessary computation.

Figure 4 illustrates one such scheme. The compressor inlet pressure P_1 and the outlet pressure P_2 are measured by electrical-output pressure transducers. The relevant equations are:

$P_2/P_1 = P_r$ actual pressure ratio, by definition

$P_2 = P_r P_1$

$P_2 - P_1 = P_r P_1 - P_1 = P_1(P_r - 1)$

$(P_2 - P_1) - P_1(P_r - 1) = 0$

A differential pressure transmitter produces $P_2 - P_1$. Now, if the signal P_1 is multiplied by a potentiometer setting representing $P_r^* - 1$, and the signal is fed into a controller, the controller operates on an error determined by the difference between actual P_r and desired P_r^* pressure ratios. P_r^*—1 is simply a matter of scaling the set-point dial on the controller.

The error signal seen by the controller is: $E = (P_2 - P_1) - P_1(P_r^* - 1)$. But P_2 is $P_r P_1$. Therefore:

$E = (P_r P_1 - P_1) - P_1(P_r^* - 1)$

$E/P_1 = (P_r - 1) - (P_r^* - 1)$

$E/P_1 = P_r - P_r^*$

This last equation shows that the controller operates on the difference between actual and desired pressure ratios. Variations in P_1 change the gain of the system, but this is easily corrected with a second potentiometer on the P_1 transducer.

The simplest way to keep the compressor away from the surge region is to blow off some of the output air to atmosphere (or to the compressor inlet). The controller operates the blowoff valve through a fast-response electrohydraulic servo that gives timely protection to the compressor.

The desired pressure ratio P_r^* must be set at some value less than the known surge-point to compensate for instrumentation and dynamic

tracking errors in the control system. However, the closer P_r* can be set to the surge-point, the more efficient is compressor utilization. This is an example of a better control system improving process efficiency.

An integral-mode added to the controller offers an advantage. If the pressure ratio is below the set-point the controller attempts to increase pressure ratio by closing the blowoff valve to prevent air waste when the compressor operates below surge.

Gain compensation

Tests made in a blowdown wind tunnel last for only a few seconds. When the gate valve opens, the high-pressure air in the storage chamber discharges rapidly through the stilling chamber, through the nozzle, and into the test chamber. Control must thus take place under transient conditions—the wind tunnel never reaches useful steady-state.

Because of the large variation in pressure between the time the test starts and the time it ends, a control loop whose gain is a function of pressure magnitude may provide satisfactory control at one set of conditions but may be sluggish or unstable at another. The variable gain in the surge control problem was compensated for by correcting it as a function of P_1.

In blowdown wind tunnels, Figure 1, change in control-valve gain, as a function of pressure drop across it, is the prime contribution to the gain changes around the loop. The input to the control valve is a valve position ordered by the controller and final control element (power servo). The valve's output is a flow of air, primarily determined by valve-stem position and valve characteristics, but also dependent on other varying conditions.

A general equation for compressible flow through the control valve is:

$$W = K(Ph/T)^{1/2}$$

where: W is the flow in lb/unit time (weight flow)
K is a known static function of valve stroke (or valve angle)
P is the pressure upstream from the valve
h is the pressure drop across it
T is the temperature of the compressible fluid at the valve

Pressures and temperatures are measured in absolute units. K carries all necessary constants.

Of particular importance in blowdown wind-tunnel work is the fact that critical flow exists at all times through the control valve. Although the flow through the valve is a function of P and h, when h is large the output pressure $(P - h)$ is negligible and the flow is determined by P alone. Thus, as the output pressure is decreased to the point where it no longer affects the flow rate the flow equation is replaced by one in which P enters to the first power (rather than square root) and the flow is said to be critical. With air as the fluid, when the output pressure of the valve $(P - h)$ is less than (about) 0.53 of the input pressure P, the flow through the valve is critical. Under critical flow, with reasonable accuracy, h can be replaced by $P/2$, and the flow equation can be rewritten:

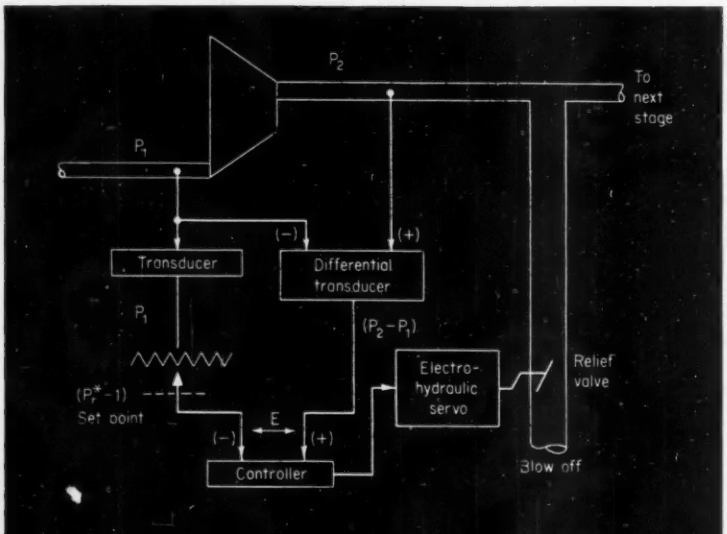
$$W = K'P(T)^{-1/2}$$

The weight flow depends on the open area of the valve, which in turn depends on its geometric relationship to valve stroke. The resulting nonlinear changes of static valve gain with valve opening can be linearized over the operating range by linkages in the valve-operating mechanism or by a characterized feedback in the controller's final element. This is a simple way to compute the compensation necessary to maintain the K' portion of the valve gain at a constant value.

But the above equation also shows that a change in inlet air pressure or temperature, or both, to the valve will change the flow for a fixed valve stroke. Thus, in addition to being a function of valve stroke, valve gain is also a function of pressure and temperature. In blowdown wind tunnels the variation in inlet pressure P will be large when the storage chamber is evacuated during the test from a high initial pressure to a low final pressure. Furthermore, the stored air may be hot if it has recently been pumped into the storage chamber and it will cool rapidly as it is released. These variations in pressure and temperature are large enough to have a marked effect on valve gain and system response.

One way to compute the gain compensation for changes in pressure and temperature is shown in Figure 5. Here, pressure and temperature transducers are introduced between the controller output and the valve positioner with characterized feedback. The pressure transducer corrects for the effect of pressure on control-valve gain by reducing the ordered valve stroke for increasing pressures. The temperature transducer contains a square-root cam (or potentiometer). Temperature is entered by modifying the signal from the controller to the valve, i.e., by calling for increased valve stroke for increased temperature. Thus, the characterized linkage or feedback, the pressure compensation, and the temperature compensation elements compute, in a very simple manner, the overall gain correction necessary to maintain a stable control loop.

FIG. 4. Details of surge controller used in continuous wind tunnels, Figure 2, that computes pressure ratio to maintain stable compressor operation.



Density correction

In metering the flow of a compressible fluid (air, in the case of a wind tunnel) by means of a pressure drop across a calibrated orifice, the weight or volumetric flow through the orifice is a function not only of the pressure drop across the orifice but also of the density of the air. But air density depends on air temperature and pressure. Thus, appropriate computation based on pressure and temperature measurement can yield a density correction for the weight or volumetric flow control.

Figure 6 shows a method for computing density correction for air-flow

control in the wind-tunnel ducting. Here, the differential pressure across the orifice determines the air flow, which is the controlled variable in the control loop. The flow controller, in the arrangement shown, attempts to maintain flow at some set value.

The orifice equation is the same as the valve equation used in the section on gain compensation, and can be rearranged to:

$$h = K_2(W^2T/P)$$

For a given weight flow through the orifice, the differential pressure will be affected by the density of the air as represented by temperature and pressure, and will be a true indication for only a particular calibrated T and P. For other values of temperature and pressure a density correction must be computed and entered into the controller.

If the differential pressure signal h is multiplied by the ratio of pressure and temperature:

$$hP/T = K_2W^2$$

the resultant corrected signal would be a true indication of weight flow. Actually, as shown in the equation, the differential pressure is a function of flow squared. This means that the set-point of the controller must be calibrated in flow-squared units and that there will be a loop-gain change at different flow rates.

Returning to Figure 6, pressure and temperature transducers vary their resistances in proportion to their respective variables. These resistances, together with a feedback potentiometer, form a bridge circuit excited from a constant-voltage source. The bridge is continuously forced to balance by an amplifier driven motor geared to a shaft to which the feedback pot is attached. The bridge will be in balance, and the motor will stop turning, when the impedance ratio of the two lower arms equals the ratio of the two upper arms.

The ratio of the two upper arms is, of course, P/T needed for density correction. The motor shaft will have rotated through an angle representing (but not proportional to) the ratio of pressure to temperature.

The differential pressure h is converted to a force by the diaphragm. The density correction is entered on a ratio slider that changes the position of fulcrums in a leverage system whose force output is then differential pressure multiplied by density correction. This output force opposes another force, a spring, representing a weight-flow rate set-point. A difference in forces moves the jet pipe of a hydraulic valve that, through a crank-type cylinder, positions the control valve until the density-corrected differential pressure is equivalent to the preset weight flow.

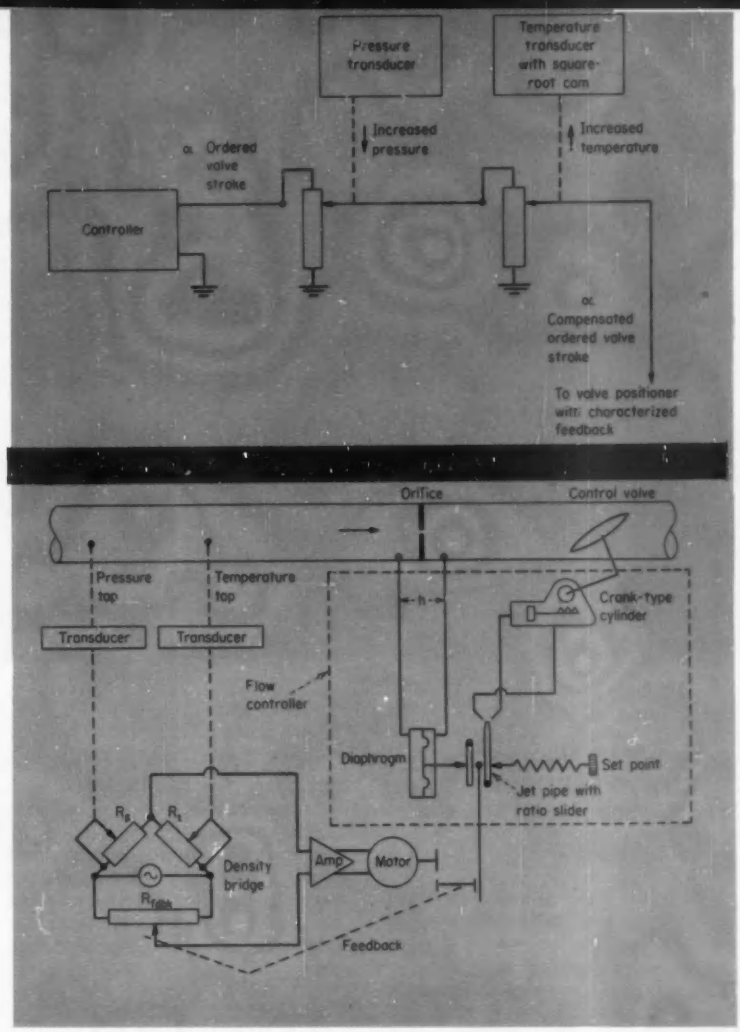


FIG. 5. Gain compensation used in blowdown wind tunnels assures fast response and stability at all conditions.

FIG. 6. Density correction computation assures controlled weight flow independent of changes in air pressure and temperature. Interchanging R_p and R_t gives density correction for controlled inlet volumetric flow.

Recall that in the surge control problem the pressure ratio was a function of inlet volumetric flow, not inlet weight flow. The scheme shown shown in Figure 6 can be used for density correction in the surge-control loop merely by interchanging the positions of the pressure and temperature resistances in the bridge. This makes the motor angle at balance representative of the temperature-to-pressure ratio.

The differential pressure:

$$h = K_2(W^2T/P)$$

is multiplied by the ratio of temperature to pressure:

$$hT/P = K_2(WT/P)^2$$

From the equation of state of a perfect gas it is known that:

$$PV = WRT$$

where R is the gas constant. Therefore:

$$WT/P = V/R$$

Thus, the density-corrected differential pressure signal becomes:

$$hT/P = K_2V^2$$

where V is the volumetric flow through the wind tunnel. With proper calibration of the set-point, the control loop maintains a preset density-compensated volumetric flow.

Computing-Control Applied to an
AIRBORNE FIRE-CONTROLLER

Computing-control of airborne gunnery systems represents a mature application of computers to process control. The particular system discussed here tracks another aircraft, determines ballistic and kinematic effects, and computes the necessary prediction angle for a projectile.

Specific details about any one airborne fire-control system remain under security wraps. However, the authors point out the input information needed by the computer, show how exact equations are found by using a ground-based digital computer, and discuss the equipment actually used as hardware to solve the necessary prediction angle equations.

ROBERT C. PFISTER
E. EDWARD BUDER
The Emerson Electric Mfg. Co.

Shooting down one aircraft from another involves problems in combat that can only be solved by a high degree of computing and control. This is because many of the combat functions once performed by a human operator are now performed in a more exact and integrated way by the gunnery system itself. Among these are: automatic target tracking and ranging, maneuvering of the gun turret (this is impractical for a man to do when the gun is in a slip stream of a high-speed aircraft), and computer-controlled aiming.

Figure 1 shows the major components of a typical airborne fire-control system. For the sake of clarity, only a single axis is considered here; actually the radar and turret systems move on two gimbal axes, those of azimuth and elevation.

The function of a fire-control computer is to aim a weapon so that projectiles intercept, in space and time, a rapidly-moving enemy aircraft and destroy it. This requires the continuous calculation of the angle between the present line of sight to the target and the correct weapon-aiming line. This angle in space is known as the prediction angle. The calculations to find the prediction angle necessitate the extrapolation of both the projectile path and the target path during the projectile's flight time. Hence, the term prediction is fully appropriate.

Dynamic performance of the fire-control computer influences its design. Some dynamic considerations are inherent noise in the inputs; the specific control response necessary to stabilize the overall tracking and prediction loops; and the effects of computer dynamics.

The prediction problem

The gunnery prediction problem results from two major effects: kinematic and ballistic corrections. Kinematic correction, which results from the perceived motion of the target during the projectile's flight time, must itself recognize two effects:

1. Absolute motion of the target aircraft rotates the line-of-sight to the target.

2. Absolute own-ship motion also determines line-of-sight rotation. The resultant correction angle of the weapon-aiming line is called the lead angle, L in Figure 2.

This figure also indicates a deviation, called the ballistic correction angle B, of the actual projectile flight path from the weapon-aiming line. This is the consequence of three more (independent) effects:

1. Gravitational forces on the projectile cause a curvature of the trajectory.

2. Velocity loss of the projectile as it traverses the trajectory causes an apparent trajectory curvature. This effect is commonly called windage curvature.

3. For projectiles fired crosswind, the interaction of aerodynamic forces with the gyroscopic properties of the spinning projectile causes a damped spiraling motion of the projectile (see Figure 2). This motion damps along a line other than the weapon-aiming line. The resultant displacement from the weapon-aiming line is called windage jump.

The total prediction angle P is the sum of the kinematic and ballistic angles. Figure 3 shows the input information and subcomputations needed to arrive at the prediction angle's elevation and deflection (azimuth) components. Note that the computation procedures are very similar for each axis, except that the gravity effect must be introduced into the elevation component.

The high velocities and altitudes of today's military airplanes markedly affect the design of fire-control computers. High velocities mean increased target motion during the projectile's flight time, and thus a larger lead angle to be corrected by the computer. However, all this is partially offset by the less dense atmosphere at the higher altitudes.

A more complex relationship exists between windage jump magnitude and aircraft velocity and altitude. Windage jump increases with aircraft velocity because of both the larger projectile yawing angles and the decreased projectile velocity in the air mass. At low altitudes the spiraling motion of the projectile may be neglected because of the short projectile range at which

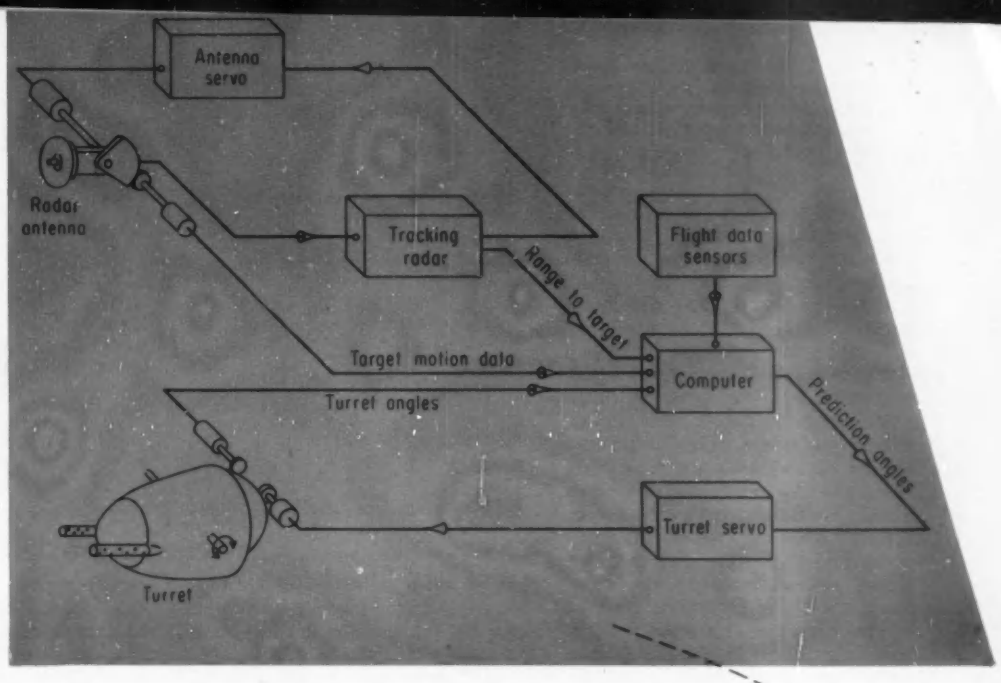


FIG. 1. The airborne fire-control computer receives tracking and ranging information about the target aircraft from a closed-loop radar antenna system. This information, along with flight data and turret-direction information, is used to develop prediction-angle signals for two turret gimbal axes, azimuth and elevation. The block diagram for one axis only is shown here.

damping is completed. But at higher altitudes the damping decreases. The computing-controller must therefore account for all aforementioned changes in ballistic characteristics if system accuracy is to be maintained.

Before exact fire-control problems can be solved, realistic interceptor paths must be computed. Factors that affect the space paths include the interceptor's armament and aerodynamic behavior, the type of attack, and the relative aircraft positions at the start. Projectile ballistics and computer dynamic response must also be known.

Control equations

Instrumentation of exact equations is impractical—their complexity requires computational equipment exceeding permissible weight limits. However, it is possible to instrument and solve in flight a set of "calibration" equations that approximate the exact gunnery prediction problem with sufficient accuracy. Figure 4 shows the type of information needed and the procedure for determining the calibration equations in the form of hardware specifications. The complexity of the exact equations and the relatively large number of solutions require a high-speed digital computer. This computer solves the exact equations over the complete range of operational possibilities and produces numerical information that can be interpreted as families of nonlinear curves. The possible forms of the calibration

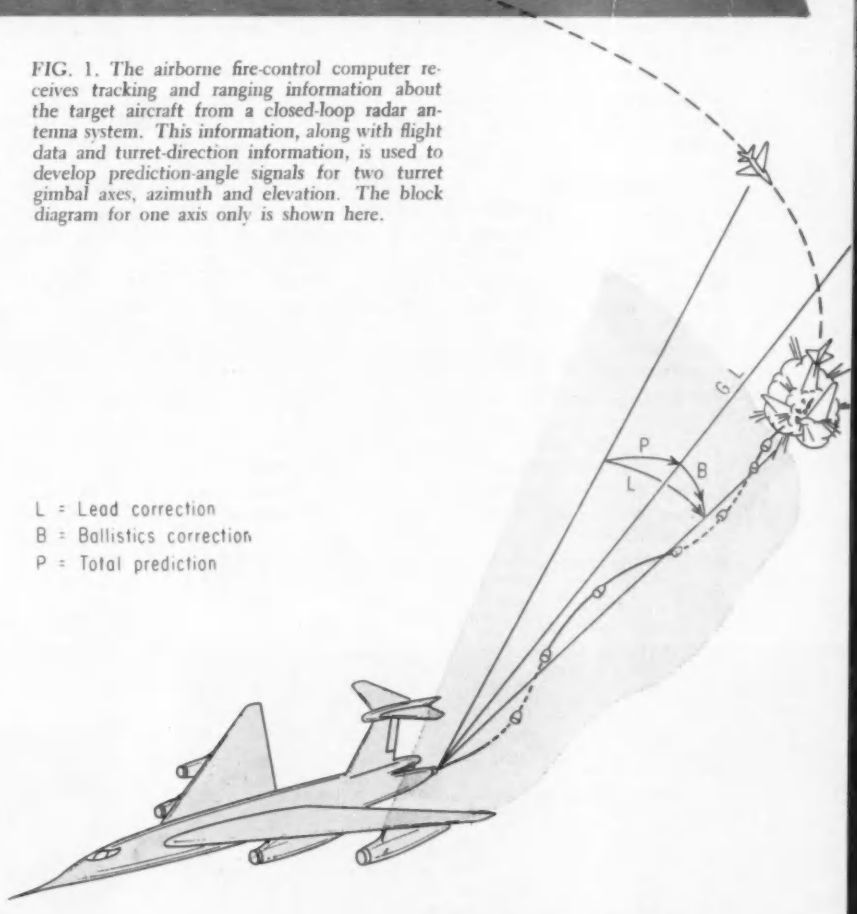


FIG. 2. Gunnery-fire control requires the solution of a space geometry problem.

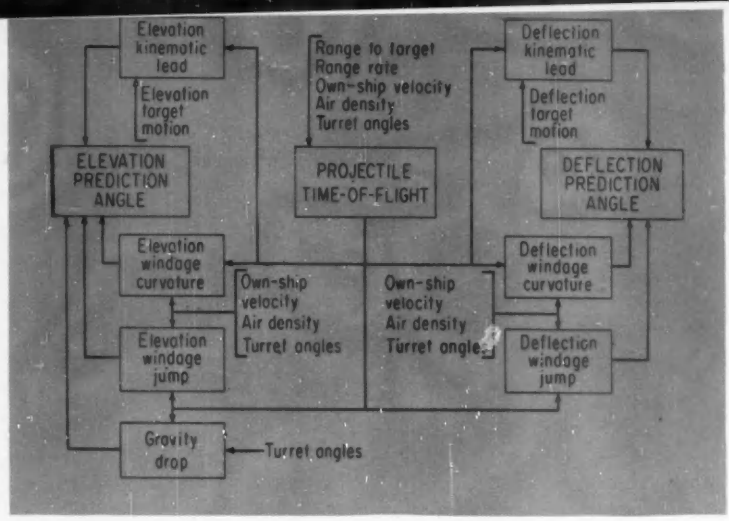


FIG. 3. This block diagram shows how the prediction angle is computed as two separate components, and indicates the input data and the subcomputations involved.

equations are then determinable from the examination of the exact solution. The adequacy of the calibration equations may readily be assessed by finding the difference between solutions of exact equations and calibration equations.

Until recently, the forms of the calibration equations and the functions of the variables were determined graphically. This meant extensive, cumbersome, and inaccurate data plotting and curve fitting. These limitations have now been eliminated by the high-speed digital computer, which this time provides highly precise numerical correlation and curve-fitting procedures.

The fire-control computer itself is usually analog in nature. Analog computers operate fast enough to meet combat gunnery requirements of high-speed aircraft, and their solutions are continuous and on-line. Furthermore, they meet the low-weight requirements.

Computer design

Fire-control computers are special-purpose units designed to military specifications. They differ from general-purpose computers in several important respects. One is that their typical problem is primarily the solution of algebraic and transcendental rather than differential equations. The differential operations that do occur are normally solved by the input transducers; e. g., gyros inherently perform time differentiation or integration of angular inputs to the computer. Another difference is that fire-control computers generally represent internal variables as ac rather than dc voltages. The attendant advantages over dc voltages are freedom from drift and gain stability.

In the special-purpose airborne fire control computer the main computing components are:

- carrier-type operational amplifiers that, with resistive mixing networks, add, subtract, and multiply by a constant
- instrument servos that, when used with nonlinear potentiometers, multiply and generate a wide variety of arbitrary functions
- electromagnetic resolvers that perform vector resolution and component transformation

Figure 5 shows the mechanization in an airborne fire-control computer of a typical trigonometric equation:

$$U_0^2 = V_M^2 + V_B^2 - 2V_M V_B \cos AZ \cos EL$$

using operational amplifiers, servos, and resolvers.

Computing-control of airborne gunnery systems represents a "mature" application of computers to process control. Indeed, it has common origins with the very concept of computational control. As such, it may be indicative of the normal development of such systems.

Two trends continue to characterize fire-control systems:

1. Any solution to a fire-control problem is ultimately obsoleted by technological advances in the aircraft and armament (the process) under control.

2. The necessity for frequent revision of fire-control systems, to be compatible with new higher-flying and faster-operating aircraft, calls for more efficient methods of designing these systems. Ground-based general-purpose digital computers, capable of rapidly solving a great number of repetitive problems and yielding families of curves, must thus support the airborne analog computer in evolving a new design. This approach also allows increasingly detailed calculation of calibrating equations to more accurately match the exact equations.

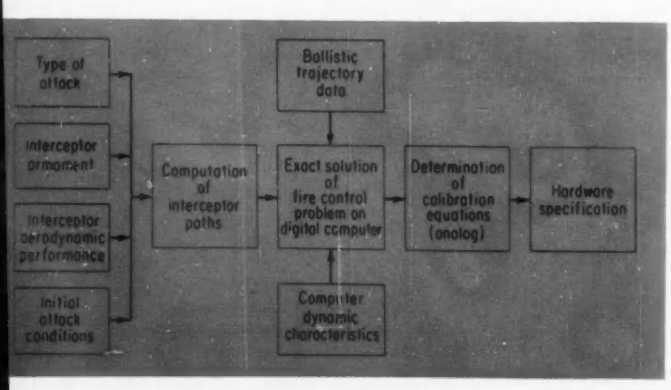
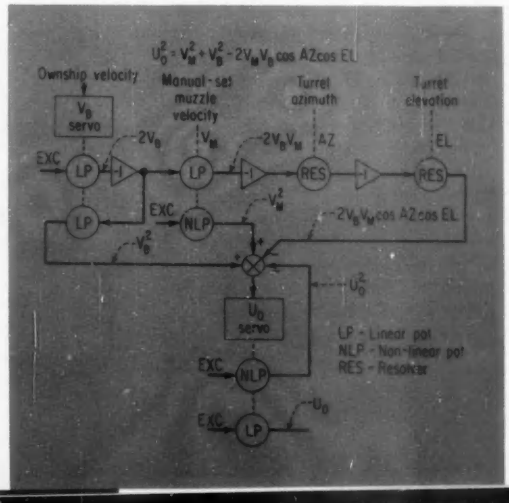


FIG. 4. Development of an airborne analog fire-control computer involves many steps before actual hardware specification.

FIG. 5. Most equations solved in the analog computer are algebraic rather than differential. Shown here is an equation that uses for its solution operational amplifiers, resolvers, function generators, and instrument servos.



Computing-Control Applied to a

TAPERED-SHEET LEVELER

Dornbusch uses a group of operational-amplifier integrators, in conjunction with amplidynes, relays, and motors, to automatically compute linear taper signals and position the leveler's work rolls. Reference signals fed into the computing integrators tilt the rolls before starting the leveling operation, thus assuring that all rolls are in the correct relative position for leveling or straightening the previously tapered aluminum sheet.

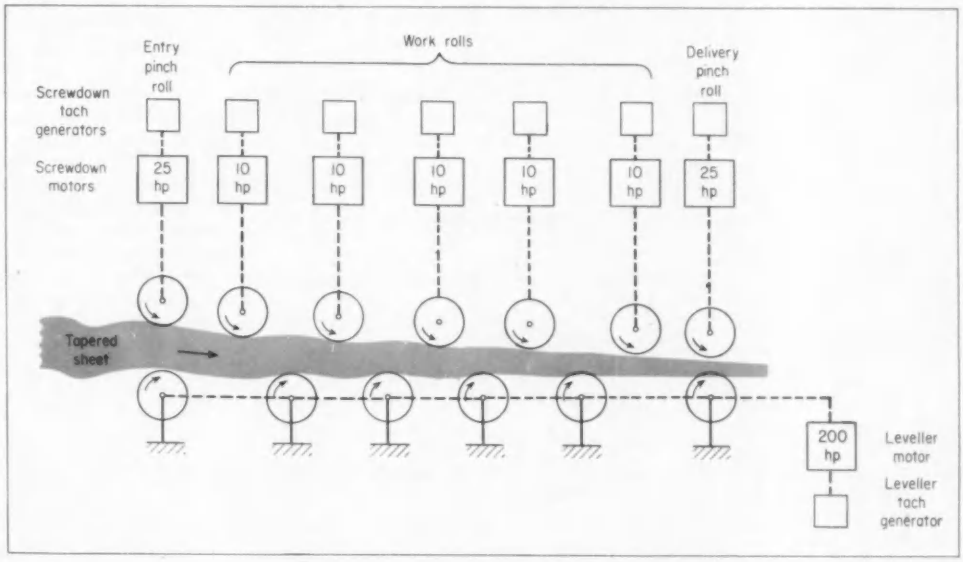


FIG. 1. Leveling mill for tapered aluminum sheet.

PAUL E. DORNBUSCH
Industry Control Dept.,
General Electric Co.

The leveling of longitudinally-tapered aluminum sheets offers another opportunity for computing-control. For certain uses aluminum sheet is rolled with a tapered rather than flat cross-section. The tapering is done by the hot rolling mill, but the tapered product is badly shaped and requires a leveling operation.

Figure 1 shows the schematic of leveling process and Figure 2 the control system. The feed stock, of tapered cross-section but bent and wrinkled from previous rolling and handling operations, moves through the leveler driven by the bottom rolls. As the sheet progresses it is is flexed by the work rolls to straighten out the bends and wrinkles. Since the rolling machine produces linearly-tapered sheet, the vertical distance between the top rolls and their associated bottom rolls must increase as the sheet moves through the machine.

The amount of thickness-increase per foot of sheet travel is the taper. Forward travel of the sheet is relatively easy to measure, but direct instantaneous measurement of sheet thickness is not practical because of the physical condition of the unstraightened sheet as it approaches the leveler. Changes in thickness as the sheet moves can be calculated indirectly and this measurement used to control the rate at which the pinch and work rolls move to maintain desired linear taper.

Speed of sheet travel (ft/sec) multiplied by the cross-section taper (in./ft) equals the rate of change of thickness (in./sec). This quantity integrated with respect to time becomes actual thickness change.

Pinch roll screwdown

Essentially a computing-control system like the one in Figure 2 carries out the foregoing calculation

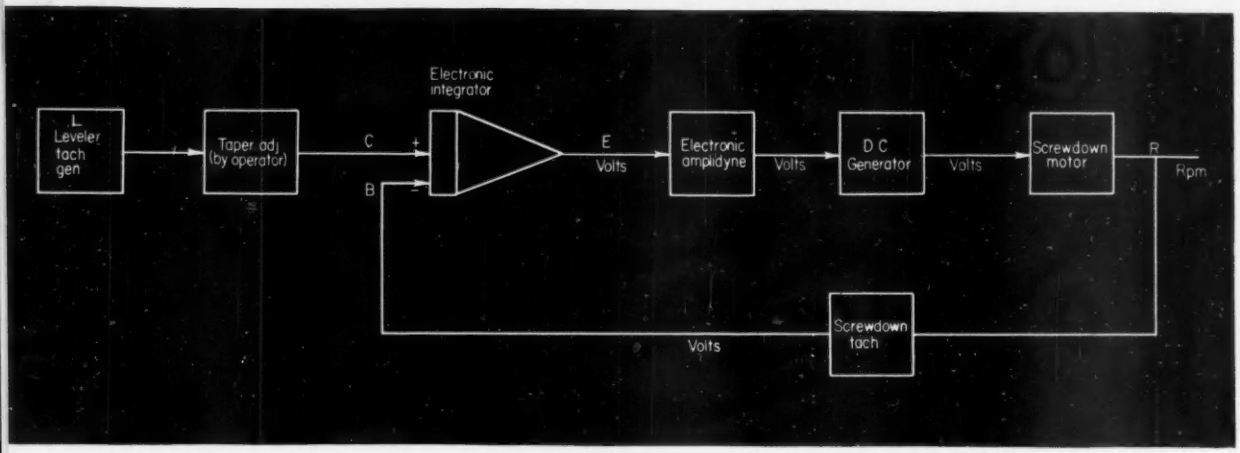


FIG. 2. Positioning system for pinch roll screwdown.

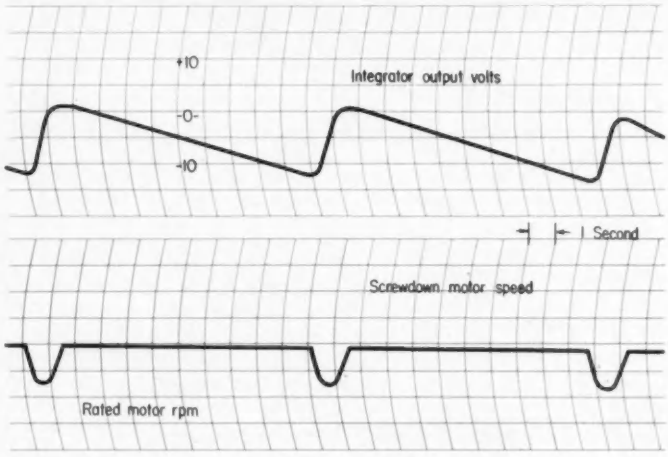


FIG. 3. Simultaneous records of integrator output error (top) and screwdown motor speed (bottom) show the step-wise correction for the work rolls. These records were taken at a forward speed of 15 ft/min and a taper of 15 mils/ft.

and integration for each work roll in Figure 1. Figure 2 is the block diagram of the position-control system for a pinch roll screwdown stand. A tachometer-generator coupled to the leveler drive motor provides a voltage signal proportional to the forward rate of sheet travel. From the specifications of the product the operator selects a portion of this voltage (taper adjustment) as the input reference to an operational amplifier hooked up as an integrator. The taper adjustment is calibrated directly in mils/ft, so that a taper of 30 mils/ft requires a setting of 30. This taper signal, C in Figure 2, can be represented mathematically as:

$$K_1V_1 = d\ (\text{thickness})/dt$$

A similar equation arises from the signal B fed back to the integrator from the screwdown tachometer:

$$K_2V_2 = d\ (\text{roll opening})/dt$$

The integral of either of these equations represents a thickness, and in the arrangement shown in Figure 2 the difference between the two integrals is a thickness error. Thus:

$$\int K_1V_1dt - \int K_2V_2dt = \text{thickness error}$$

This error voltage, amplified by the electronic amplidyne and the generator, changes the vertical position of the roll at a rate to maintain minimum thickness error, ideally zero error. Since the closed-loop control system maintains minimum error, the system computes and forces the screwdown roll to open at a rate determined by the taper preselected by the operator.

Work roll screwdown

The vertical rate at which the entry and pinch rolls retract with forward motion of the sheet is fairly critical and a continuous positioning system is used. However, the position of work rolls is less critical and the positioning scheme is simpler. An integrator computes thickness error as described previously, but correction does not occur until the error exceeds a preset value E:

$$\int K_1V_1 - \int K_2V_2 > |E| \text{ for correction}$$

The correction occurs stepwise. The error voltage accumulates on the integrator until it becomes large enough to operate a voltage sensitive relay. The relay operates a screwdown motor-starter and then the motor. A tachometer-generator on the motor feeds back a signal opposing the reference signal and reduces E until the voltage relay contacts open to shut off the screwdown motor. Figure 3 shows the integrator output E slowly increasing (in a negative direction) as strip thickness increases. The lower curve is a simultaneous record of screwdown motor speed as obtained from the screwdown tachometer. Note that when the computed output (the error) is between zero and about minus 11 volts the screwdown motor is not running and the work roll position remains constant. But when the output error exceeds the

dead zone of 11 volts the motor operates and the work roll is repositioned in a direction to reduce the error, and when the error returns within the dead zone the motor shuts off and coasts to zero speed.

Tilt computing

In this computing-control system, the average rate of movement of all rolls is equal. Suppose a line connecting the centers of all top rolls were parallel to the horizontal bottom rolls. As the sheet is fed forward the entry pinch roll would move upward in accordance with the taper requirements. When the leading edge reaches the first work roll the roll would clear the sheet because the vertical distance of all rolls has opened up an equal amount in accordance with the taper signal. The clearance at successive stands would become greater as the sheet advances. All the work of leveling would be done by the entry pinch roll, and production would be highly unsatisfactory, if not impossible.

For all seven rolls to share the work, the top rolls must be so displaced vertically that a line drawn through their centers makes an angle, equal to the desired taper, with the horizontal bottom work rolls.

Before the sheet enters each roll should be lowered an amount proportional to the horizontal distance from that roll to the entry pinch roll. To accomplish this, the operator's selector switch applies to each screwdown electronic integrator a preset voltage signal proportional to its horizontal distance. All rolls then move at a rate proportional to their individual voltage signal, and the result is that the line pivots about the reference point (entry pinch roll position) at a constant rate and the rolls stay in line. To show the amount of tilt, the selector switch also applies a reference signal to an eighth integrator, whose output is a measure of total tilt as indicated on a voltmeter calibrated in mils/ft.

Figure 4, a simplified schematic of the complete system, shows seven control loops with seven computing integrators for the seven work rolls, and the eighth integrator for tilt indication. At mill start-up, the leveler taper voltage is zero. The tilt is set in before the sheet is entered. When the sheet is entered into the rolling mill the leveler reference signal, proportional to desired taper, feeds into the integrators and the integrator output errors cause all screwdown roll top rolls to move vertically at the prescribed mils/ft taper.

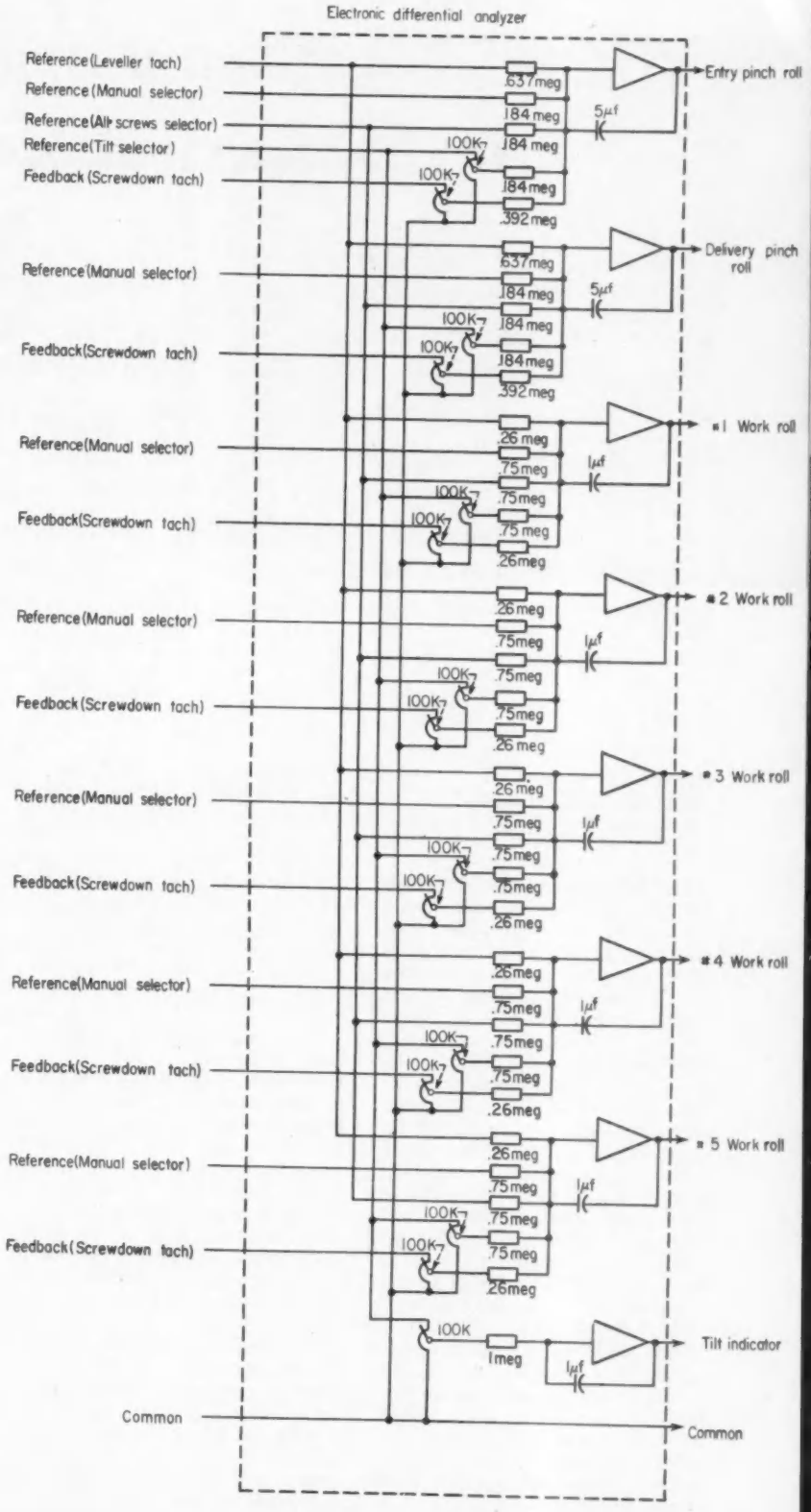


FIG. 4. Simplified schematic of the complete analog computing system for seven rolling stands and the tilt indicator.

Computing-Control Applied to a

FRACTIONATING COLUMN

Engel develops equations for the fractionation process which when solved repeatedly yield an appropriate feed tray, an economical reflux rate, and the amount of heat input for a column top-product of specified composition. He describes the program of a digital computer designed to carry out the calculations and to indicate the results on a display board. Initially, the system will have a human operator reading the information on the board and manually adjusting process conditions. But operating experience is expected to result in a closed loop incorporating the computer, time-shared with several fractionators.

HOWARD L. ENGEL
Computer Systems Div.,
The Ramo-Wooldridge Corp.

Distillation is the process of boiling off a vapor component from a multicomponent liquid and then recondensing the vapor by cooling. A mixture of two or more liquids can be separated by multiple distillation, in which the condensate from the first distillation becomes the raw material for the second. This may be done with several simple stills or with an equivalent single unit known as a fractionating column. Inside the column may be a number of bubble-cap plates which bring the liquid and vapor into contact so that the necessary mass transfer occurs. Each plate, in effect a simple still, acts as the condenser for the vapor from the plate below and as the source of vapor to the space above.

In the continuous fractionating column, the feed material enters at any one of a number of trays in the middle portion of the column. One product is removed from the top of the column and another from the bottom, and other products may be removed at intermediate points. One control objective is production of a top product of a desired composition. This will be the objective assigned to the computer-controller. (Another objective could be the maximizing of dollar value of fractionation products.) The actual computations required for column control can be expressed simply, but they are tedious to perform manually. Consequently, such control is an excellent application for an industrial control-computer.

Column operation

The operation of the column depends on:

- relative vapor pressures of the materials involved
- tray number at which the feed material enters
- composition and feed rate of the feed material
- desired composition of the product or products
- distillation efficiency of the plates (trays), and
- latent heat of vaporization of the feed material

Operation is complicated because the effectiveness of distillation depends on the rate at which the product is removed from the top. To obtain a larger fraction of higher-vapor-pressure material at the top it is necessary to recondense a portion of the top vapor and feed it back into the top of the column as a liquid. There are then two flows in the column: enriched vapors flowing upward and a liquid traveling downward.

Figure 1 shows two bubble plates in a column cross-section. The vapor traveling upward forces its way through the bubble-cap and is absorbed in and adds volume to the liquid on the plate. Liquid is also added on the plate by overflow from the plate above. Some evaporates to the space above and some overflows the weir to the plate below.

Separating a binary mixture

In a mixture of two liquids (that mix without complicating effects such as chemical combination or molecular association) the partial pressure of any component equals the vapor pressure of that component in the pure state times its mol fraction in the liquid mixture (Raoult's law). If a mixture of two liquids is placed in a closed container with a space above for containing vapors the total pressure equals the sum of the partial pressures of the components present (Dalton's law).

When the liquid consists of two materials, *a* and *b*, in the fractions x_a and x_b with vapor pressures P_a and P_b, then from Raoult's law the partial pressure of *a* and *b* are:

$$p_a = P_a x_a \quad (1a)$$

$$p_b = P_b x_b \quad (1b)$$

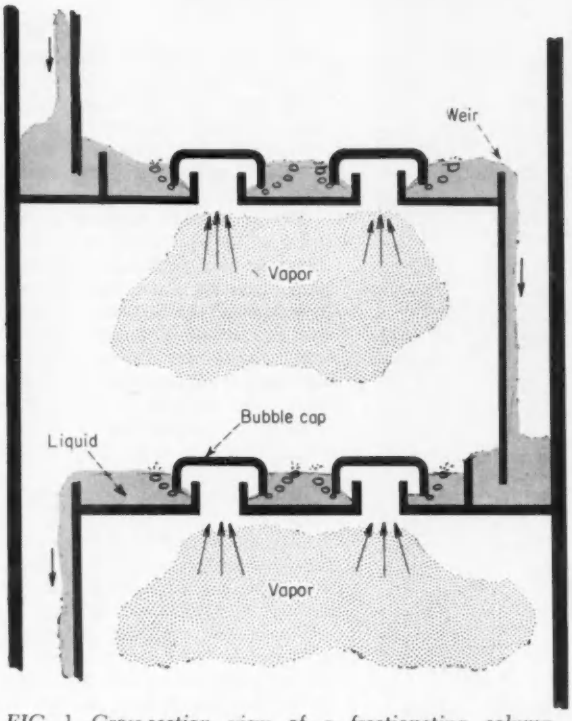


FIG. 1. Cross-section view of a fractionating column showing liquid flowing downward, vapor flowing upward.

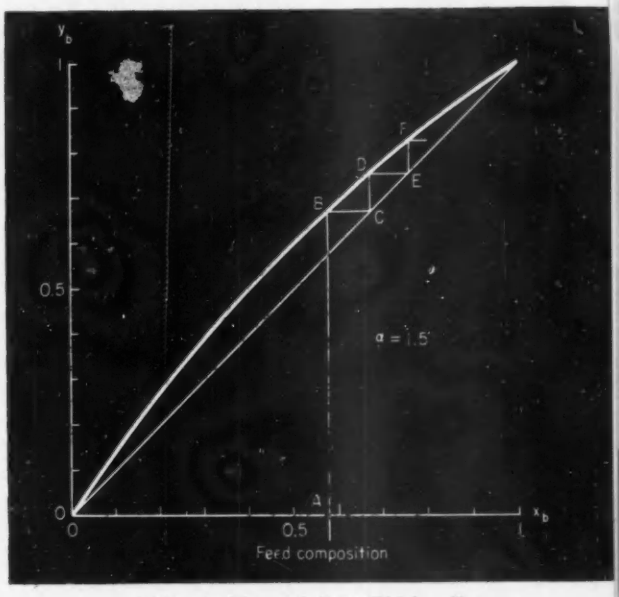


FIG. 2. The McCabe-Thiele diagram indicates the composition at each tray.

Now, let y_a and y_b be the vapor fractions in equilibrium with the liquid. Then, from Dalton's law:

$$p_a = y_a(p_a + p_b) \quad (2a)$$

$$p_b = y_a(p_a + p_b) \quad (2b)$$

Also, the total of mol fractions of vapor components is unity, and the total of the mol fractions of liquid is unity, or:

$$x_a + x_b = 1 \quad (3a)$$

$$y_a + y_b = 1 \quad (3b)$$

Letting α be P_b/P_a, the vapor-pressure ratio of two components in the feed material, the above six equations leads to:

$$y_b = \frac{\alpha x_b}{1+(\alpha-1)x_b} \quad (4)$$

which shows the equilibrium relationship between composition of vapor *b* and the liquid *b*. The heavy line in Figure 2 describes the condition when $\alpha = 1.5$. Material *b* is selected here as the top product to be distilled. An expression similar to Equation 4 can be found for the bottom product, material a.

If no material is removed and the column is allowed to come to equilibrium, then the liquid on each plate and the vapor above it are related in composition by Equation 4. Furthermore, the liquid on each plate and the vapor below it have identical composition. The change in composition from plate to plate along the column may be determined graphically by referring back to Figure 2. Here a 45-deg line aids the graphical construction. The feed composition and the vapor in equilibrium with it on the feed tray are indicated by a vertical line *AB*. Since this vapor has the same composition as the liquid above it, the liquid composition can be determined by drawing a horizontal line from *B* until the line intersects the 45-deg line at *C*. The vapor above this second plate now has the composition indicated by *D* and the vapor above the next plate has the composition *F*. Thus, the liquid and vapor compositions at various plates above and below the feed plate may be determined by a graphical technique.

On the other hand these answers can also be found by simple numerical methods. Letting x_n be the fraction of material *b* at plate *n*, the fraction of material *b* at plate *n* -- 1 (one plate below n) can be determined from a modification of Equation 4:

$$x_{n-1} = \frac{y_{n-1}}{\alpha-(\alpha-1)y_{n-1}} = \frac{x_n}{\alpha-(\alpha-1)x_n} \quad (4a)$$

This equation may be solved repeatedly to find the composition at any plate.

The situation just described exists only when no material is being removed from the column. To determine the corresponding equations when material is being removed, it is necessary to perform a mass balance under steady-state conditions. This assures that the amount of material in any portion of the column neither increases or decreases. Consider the plates above the feed plate—the column portion shown in Figure 3. An amount of distillate (top product) *D* is being removed. An amount of vapor *V* enters this portion of the column from below and an amount of liquid *L* leaves this portion to flow down the column. Thus, the steady-state mass balance is:

$$V = L + D$$

Now, not only the total mass flow, but also the mass flow for each component in the liquid, must be balanced. Between plates *n* and *n*–1 the amount of material *b* flowing upward in vapor form is Vy_{n-1} and the amount of material *b* flowing downward in the liquid is Lx_n. Furthermore, the amount of *b* leaving the column at the top is Dx_D, where x_D is the fraction of material *b* in the distillate. Since in the steady state there is no change in material *b* in any portion of the column,

$$Vy_{n-1} = Lx_n + Dx_D \quad (6)$$

Solving Equation 5 and 6 simultaneously leads to

$$y_{n-1} = \frac{x_D + Rx_n}{1+R} \quad (7)$$

where *R* is the reflux ratio *L*/*D*.

A similar analysis must be per-

formed for plates below the feed tray. The liquid flowing down, now called S, is equal in quantity to reflux L entering the top plus the feed material F, or

$$S = L + F \tag{8}$$

Below the feed tray, the mass balance (for material b) is:

$$Vy_{n-1} = Sx_n + Dx_D \tag{9}$$

Solving for y_{n-1} yields:

$$y_{n-1} = \frac{x_D + (R+Q)x_n - Qz}{1+R} \tag{10}$$

where Q is the ratio F/D and z is the fraction of material b in the feed.

The function of the fractionating column is to produce a specified mol fraction of vapor y_b at the top tray which then condenses to distillate D of desired purity x_D. The function of a computer-controller is to vary operating conditions in the column to assure that the specifications are met.

Starting at the top of the column, repeated solutions of Equations 7 and 10 yield the liquid fraction x_b

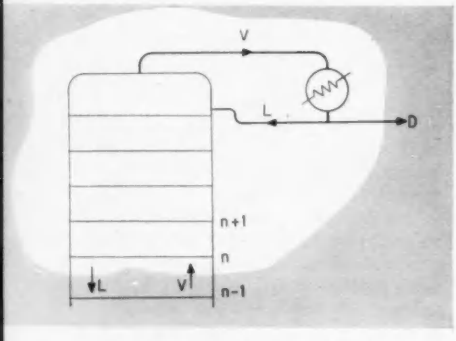


FIG. 3. Under steady-state conditions the mass of the vapor equals the sum of the distillate and liquid.

at each tray down the column. The solutions must be carried out in conjunction with a rule governing the equilibrium of a liquid and a vapor (for many mixtures the rule is given by Equation 4), and with a statement of suitable boundary conditions.

Solving Equations 7 and 10 requires explicit statement of reflux ratio R and feed-to-distillate ratio Q, factors which cannot be determined directly. This means that trial values of R and Q must be assumed and the equations solved repeatedly, by trial and error, until the assumed values equal the calculated values. The numerous calculations soon become tedious if done manually.

Solving the equations by means of the calculus of finite difference can reduce the amount of manual computation, but even this refinement is hardly worth the trouble in comparison with the time-saving possible with a digital computer-controller. The equations take the form shown by Equations 7 and 10, and are programmed in the way to be described in the next section, which covers the overall control problem for a fractionating column.

Computer program

Suppose a column has 60 trays, of which trays 20, 25, 30, 35, 40, and 45 may be used as feed trays. The maximum allowable reflux ratio is specified for reasons of economy. Also known are feed rate and composition, vapor-pressure ratio of two components in the feed, heat of vaporization of the feed liquid, and column efficiency when distilling the particular feed liquid.

The desired distillate composition is specified. To meet this specification the computing-controller must first determine and then control:

- the tray to be used as the feed tray
- the reflux rate, and
- the rate of heat input

Starting at the top of the column ($x_n = X_D$ and $n = 60e$, where e is tray efficiency) the computer solves Equation 4a for x_{n-1} in terms of x_n for each tray down the column, repeating the calculations until a tray is reached that is leaner in material b than is the feed material. This tray must be at least 3 percent leaner to provide an operating margin that will permit some small reflux ratio. The computed tray number must be divided by tray efficiency to find the actual tray at which the 0.03 leaner mixture occurs. The feed enters at the first feed tray below this point.

(The total computer program, a portion of which has been discussed so far, is shown in Figure 4. It may be fruitful at this point to review this flow diagram of the computer program to get a concise picture of what steps are carried out by the computer in controlling a fractionating column.)

After the feed tray has been established, a trial-and-error or other iterative method determines the reflux ratio that will result in the composition at the feed tray being exactly the feed composition needed to yield the exact desired top-product composition. In any of these methods, a value is assumed for R and Equation 7 is applied repeatedly, starting at the top of the column (tray 60) and working down to the actual feed tray. In general, on the first attempt it will be found that the calculated composition on the feed tray is not the same as feed composition. It is necessary for the computer to choose a modified trial reflux ratio and repeat the calculation until the necessary conditions are met. This procedure yields the value of R to be used in the solution of Equations 7 and 10 for y_{n-1}.

But Q, the feed-to-distillate ratio in Equation 10, still needs to be determined. A trial value of Q is assumed and Equation 10 solved tray by tray until the bottom of the column is reached. The calculated bottom composition x_f must be the same as that determined from a mass balance for material b for the whole column. This condition is:

$$(F-D)x_f + Dx_D = Fz \tag{11}$$

and results in the equation:

$$Q = (x_D - x_f)/(z - x_f) \tag{12}$$

If Q found from Equation 12 is not the same as the assumed Q, then a new value is tried until the two are equal or the difference between the new value of Q and the old value is negligibly small.

Once the correct value of Q is known, the top-product rate D may easily be computed from $Q = F/D$. Heat input can be computed from the top-product rate and the heat of vaporization of the feed material.

Figure 4 maps out the computer program and also shows some contingencies not outlined in the preceding paragraphs:

- it may not be possible for the column to make the desired product from the specified feed material.
- the reflux ratio may be economically unfeasible

Multicomponent feeds

The calculations for controlling a fractionating column that separates a binary mixture, then, are involved and extensive, but as can be seen, a computer performs them rapidly and automatically. The calculations for a multicomponent mixture are similar, but even more involved than for a binary mixture. Consider, for example, the case of a three-component mixture. Instead of a plane curve such as Figure 2 to describe the equilibrium relationship between the liquid and the vapor, two three-dimensional plots, Figure 5, are necessary. To solve the fractionating control problem numerically requires two sets of equations at each tray for two of the three components in the mixture. The number of calculations goes up rapidly for each additional component in the feed liquid. The greater the number of calculations, the greater the justification for a computing-controller on the fractionating column.

Practical column control

The foregoing analysis assumes steady-state conditions in the column. This is a practical situation, since any disturbances affecting the column usually vary slowly with time and during the short computing interval the conditions would be essentially constant. A gradual reduction in feed rate is one such slowly-varying disturbance. Another might be a gradual change in feed composition. Short-duration rapid disturbances will be corrected by the inherent attenuation due to the large mass in the column and by the conventional controllers installed for dynamic stability.

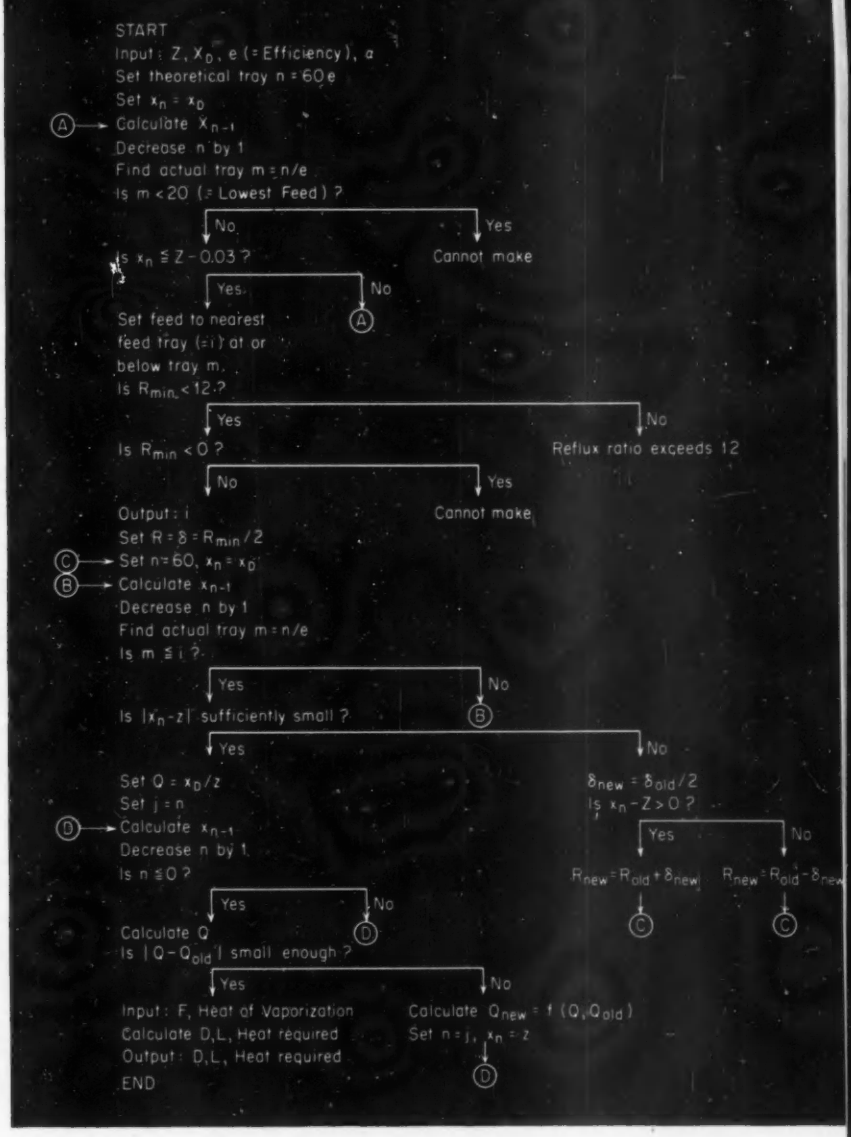
A major change in feed material composition or a new specification for top product may occur. But this will be infrequent and when it does happen can be considered predictable. It can be accounted for by altering the computer program.

The computer-controller outlined above has been constructed for demonstration purposes and the selected feed tray, the reflux rate, and the rate of heat input are displayed on a simulator board. Because of its slowly varying disturbances, the initial application of this computer-controller will probably be to instruct the operator in resetting conventional controllers, using input data obtained by conventional means. To simplify operation the input data may be inserted in analog form just ahead of analog-to digital converters. The required heat input, the selected feed tray, and the reflux rate would be read from the display panel by a human operator, who then would control the process accordingly.

On-line continuous control can be obtained by connecting all measuring instruments directly into the computer, which determines the operating conditions and sends signals to the feed tray selector, heat input, and reflux rate actuators. Composition measurement of the feed mixture may be obtained, for instance, by measuring the infrared absorption of a sample of the mixture. A flow meter determines feed rate.

Even a relatively low-speed digital computer can perform in a few seconds the calculations necessary for controlling a binary fractionating column. However, because of the slow disturbances, the calculations are done infrequently, and a large amount of computer time is not used. This time can be shared by a number of fractionating columns, with the computer program altered automatically for individual column conditions and efficiency.

Fig. 4 Program for computing - control of a fractionating column



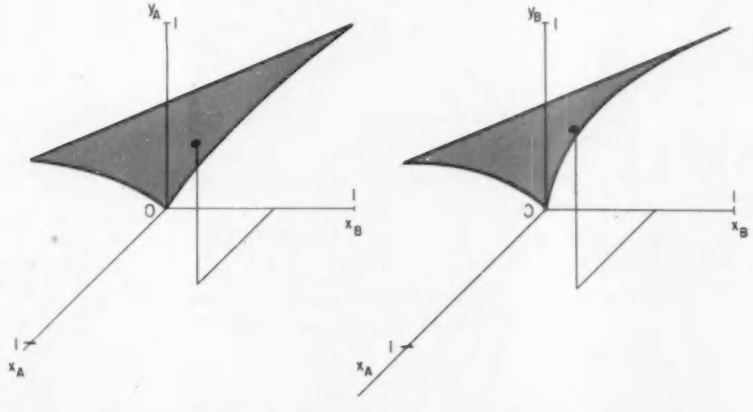


FIG 5. Two three-dimensional curves are needed to graphically describe the liquid-vapor equilibrium conditions of a three-component feed.

How to Establish the Control Problem for an On-Line Computer

EDWARD W. JAMES, E. I. du Pont de Nemours & Co., Inc.

AARON S. BOKSENBOM, National Advisory Committee for Aeronautics

THE GIST: When a computer contains an adequate characterization of a process its solutions guide and control the process. Authors James and Boksenbom present four ways to achieve this characterization: by analysis, using the basic laws of nature; by statistical correlation of operating records; by exploring response surfaces from process tests, and by a matrix description of interaction between variables in multi-loop systems.

But hand-in-hand with characterizing the process goes the need for a full understanding of the computing-control objective. This means being able to specify performance criteria and process disturbances from which the control functions and computer program can be determined. The authors discuss these points, too.

Computers capable of digesting large quantities of information, calculating answers rapidly, and delivering signals to a process await service as controllers. The principal obstacle is the difficulty in many processes of defining the process characteristics and control functions in a way that can make use of computer capabilities.

Any control problem can be visualized in the form of Figure 1, which shows the generalized process, its controller, and the inputs and outputs associated with the process and controller. The problem is formulated by specifying:

- outputs to be controlled or optimized,
- inputs (disturbances) that upset the process, and
- inputs to be used as controls.

In addition, a criterion of acceptable static and dynamic performance must be stated. Specifications for inputs and outputs include their average values, expected ranges, danger (alarm) limits, wave form, and other individual characteristics.

Process random upsets may be fast changes or slow drifts. To maintain control, each random upset must have an equivalent combination of manipulated variables that has a compensating effect on process performance.

The effect at the process output of some of these upsets can be anticipated by measuring the upset itself. In this sense upsets represent predictable error signals. Those predictable upsets that cannot be removed by design or operating changes can be introduced in a feed-forward path as an anticipated compensation to other control action. Although feed-forward improves control, residual deviations in this open-loop compensation can be reduced only by feedback elsewhere in the system.

Some upsets are not directly measurable but can be calculated from two or more primary variables. They are therefore also predictable. Catalyst activity, for example, diminishes as a specific function of temperature, time, and total material converted. The calculated loss-in-activity signal compensates the system by establishing a new set of conditions.

External inputs furnish operating criteria determined by management and by natural physical limitations. The former include such interrelated operating factors as the economics of competitive products that can be processed on the same equipment and the economic relationship between yield efficiency and productive capacity. Natural limitations are imposed by such external engineering data as maximum allowable temperatures and pressures. Without

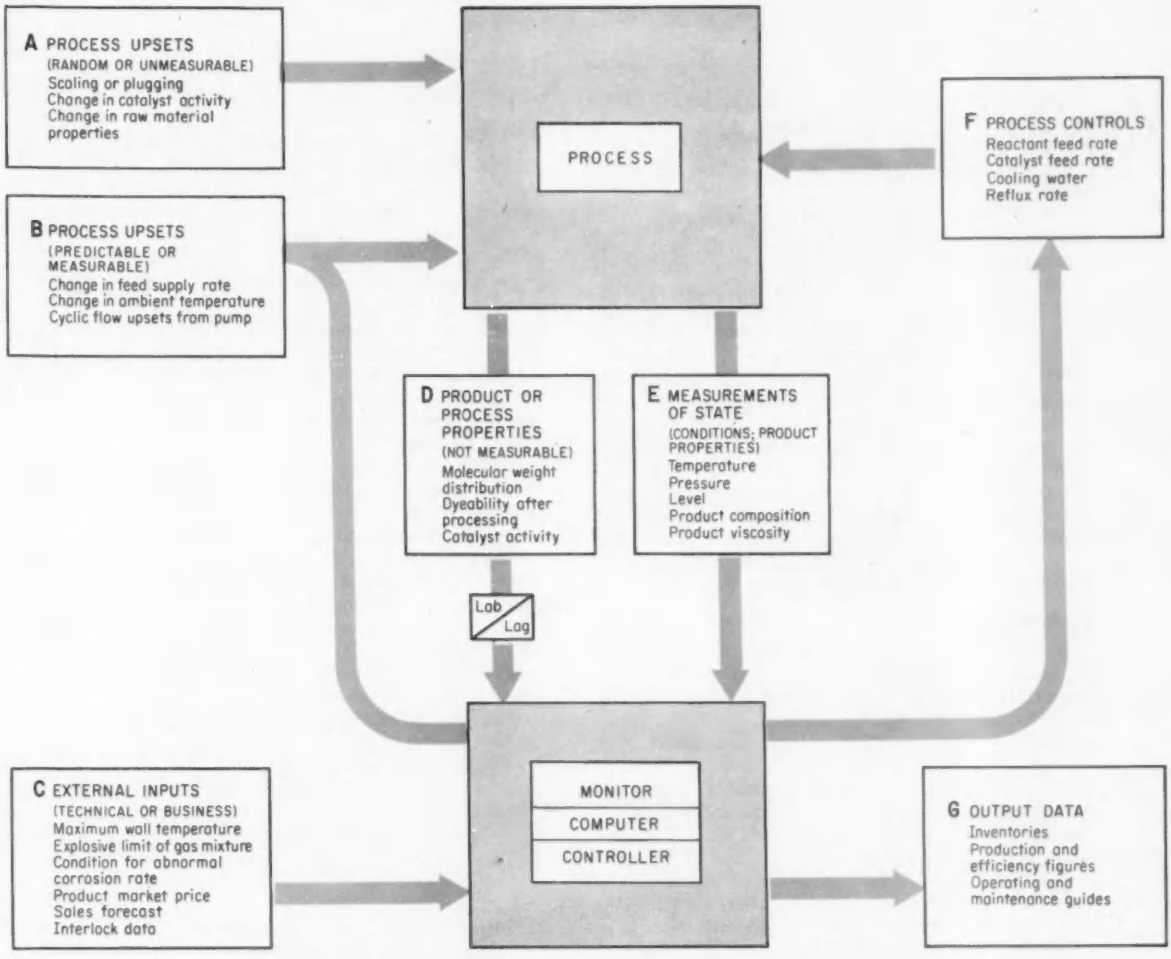


FIG. 1. Generalized process control diagram showing location of inputs and outputs. The inputs and outputs here are given in terms of a chemical process; analogous situations may exist for other processes.

limitations on process conditions an optimizing controller seeking an optimum through whatever combination of variables it requires, might call for a dangerously-high speed or pressure, or a temperature that would degrade the product. Other external variables are interlock requirements and special programmed operations (like automatic shutdown).

Some properties of the product determine whether it will be salable at a competitive price. Other properties, internal to the process, are useful for operation. These are not necessarily measurable, but if needed for system control must be calculated from input data or from output measurements. Note, in Figure 1, that the effect of these variables may be delayed, as in the case of a laboratory analysis of the product.

Measurements of state are those variables that describe the state of the process and particularly of the product. In general, measurements of state are limited by available instrumentation. Often one primary measurement, like product composition, can preclude the use of several secondary measurements, like temperature and pressure, to provide the same or better control of product quality.

Process controls, the handles on the process, are the manipulated inputs that compensate for upsets. Thus automatic valves and pumps change input flow rates to affect output. As far as an automatic system is concerned, a manually operated valve does not represent a controllable input unless, of course, a human operator supervises valve operation in response to process measurements.

Output data indicate process performance. Some data used for direct control of the process may also be recorded on charts or data loggers. Other output data contain historical information, such as inventory figures and production rates, which—while useful—may never be used for direct control.

Output data can also be records of operating and maintenance guides. Operating guides assist in the technical operation of the process; they may inform the operator when to recharge a catalyst bed or they may indicate process efficiency. Maintenance guides keep track of the severity of equipment usage and inform the process operator, for instance, when a pump requires preventive maintenance.

Disturbances

The only reason for a regulatory control system on a process is that the process is subject to uncontroll-

able and unpredictable disturbances that force it from the desired state. The control system brings the process back to the desired state. A designer of a control system must, therefore, understand the nature of possible disturbances.

The duration of the disturbances, in relation to the response speed of the control system and the time constants of the process, must be considered. A rotor speed control on a turbojet, for instance, responds to disturbances within milliseconds, while a large distillation column takes many minutes. In any case, the frequency response of the process determines the maximum frequency of disturbance that can be suppressed by a control system.

An important factor in computing-control bearing on the relation between disturbance and process frequency response is the relative slowness of the computer, particularly if it is time-shared to control other processes. Because of this, the relative response speed between a computing-controller and the disturbances it corrects could well be in the same ratio as a conventional control and the disturbance it corrects.

Performance

Just as each process requires a unique arrangement of equipment and controls, so does it need a precise definition of expected performance. There are many ways to state performance criteria, such as percent overshoot, damping factor, integrated absolute error, and static accuracy. These enable the designer to place numerical values on performance and are useful in comparing several control settings or arrangements for the same process. But they do not necessarily mean much when comparing two different processes.

Process limitations and requirements often play an important part in specifying process performance. This can be demonstrated by the response curves of three different processes subjected to a step-change disturbance, as shown in Figure 2. Figure 2A shows the temperature response of a batch formulation in which it is desirable to get up to operating temperature as soon as possible to minimize processing time. However, an overshoot of even ½ deg would ruin the batch. Therefore, a heavily-damped response is used.

Figure 2B illustrates a case where it is imperative to get the temperature of a polymer line up to operating level as soon as possible to prevent the material from solidifying (freezing) and plugging the line. Here, the relatively large swings in temperature (little damping) are acceptable as long as the temperature never falls blow the freezing temperature after once reaching it. Figure 2C shows the type of performance needed for a process in which the product becomes scrap whenever the temperature goes above or below an acceptable temperature zone. The control system for this process must have only a moderate amount of damping. It allows the process to reach the operating zone at a moderately fast rate (to reduce the time during which scrap is produced), yet minimizes cycling duration and amplitude during the rest of the processing time.

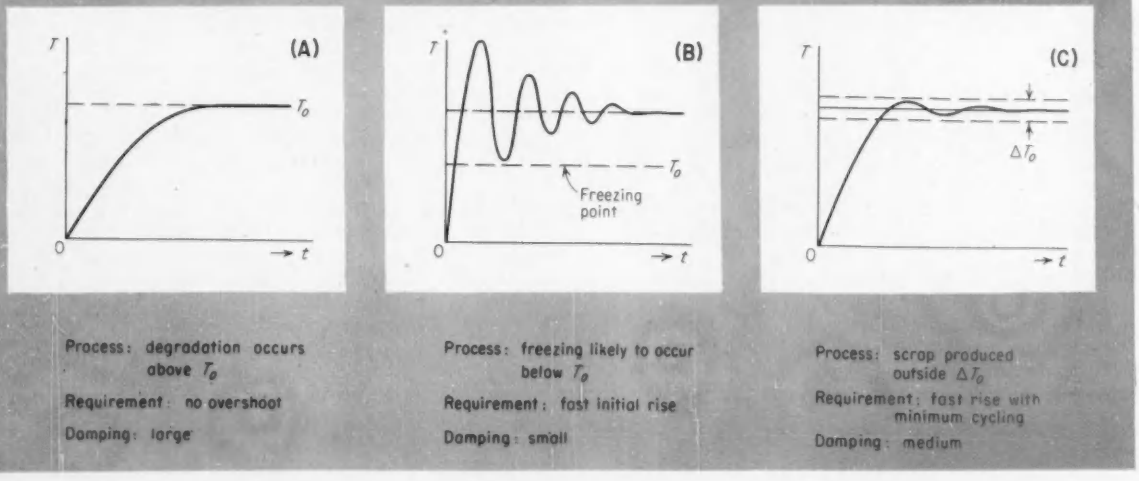
The three responses in Figure 2 may well have the same numerical value of a performance criterion (integrated absolute error) and yet they must be quite different to meet individual process requirements.

These performance characteristics refer only to single-variable control systems and they are therefore quite simple. In multivariable control several such responses must be evaluated at the same time, and statements and evaluations of performance become more complicated, particularly since each variable may have an effect on the others.

The present thinking about computers for control limits them to supervisory or optimizing jobs only. Conventional instruments will still be used for some time to control individual loops, with the computing-controller periodically determining optimum set-points and adjusting conventional controllers. This means that computer failure would only affect optimization, and would not result in complete plant shutdown. But it also means that a computing-controller must be reliable enough to operate continuously for weeks and months, with an occasional error—to be checked by the computer program discussed in a later section—but no catastrophic failure. When computing-controllers are used for direct control, the reliability requirements become more stringent.

Also, computing-controllers can operate with shorter word lengths (fewer significant figures), because final control-signal accuracies are determined by basic

FIG. 2. Performance criteria must be tailored to the needs of the process.



measurements and transmitters, and these usually have accuracies no better than 0.1 percent. Shorter word length means less computing equipment liable to failure. These characteristics considerably affect the design of the computer, and its program.

THE CONTROL FUNCTION

With the advent of complex processes, simple control functions themselves became too complex for satisfactory performance. The progression in an actual plant from manually-controlled independent loops to optimized control demanded by improved productivity could easily result in 50 or more major interacting control elements. Some attempt at optimization then presents a formibable task, even on slow processes having large hold-up capacities. And if the process is also designed to have minimum storage capacities to reduce capital investment, the control problem becomes even more complex. The need for a compact methodical control system that can make logical decisions for each control element becomes apparent.

Control and optimizing

The control equations for a process relate the actions of the valves, pumps, servos, motors, and other final control elements to the measured variables. They may take a variety of well-known forms: on-off, three-mode (proportional, reset, and rate); sampled-data; and programmed on-off (full on, full off, with a computed switching point). The equation form used depends on how much is known about the process to be controlled and a cost justification of mechanizing and implementing the form selected.

Optimizing, essentially a super-control function, has many aspects exactly similar to ordinary control. Its purpose is to maintain certain variables at their best values—in spite of random disurbances—by calling for an appropriate combination of process conditions. Calling for the best values of variables immediately eliminates the possibility of maintaining variables at fixed set-points by feedback control: an optimum yield of 97 percent may be best for one set of conditions while 92 percent may be best for another.

The computer program

At best a computing-controller of any appreciable size will be costly, complex, and require special maintenance. But it becomes justified as more and more functions are performed in addition to the basic ones of direct control and optimizing. There may never be adequate justification based only on equipment or labor savings. Improved quality and increased production capacity help, but the real incentives will come through a sharp reduction in capital investment because of the possibility of controlling fast low hold-up processes to make quality product, and through the ability to control lucrative processes not controllable by conventional means.

Here are some functions that can be obtained by using large-scale analog and digital equipment in conjunction with the best combination of measuring and analysis instruments:

- Control
- Optimizing
- Logging of production and inventory information
- Computation of operating guides
- Computation of maintenance guides
- Complete alarm and interlock system
- Automatic start-up and shutdown
- Automatic production level changes
- Calculation of unmeasurable intermediate variables
- Automatic transfer function determination

In addition to these specific services, the computer provides many program details for individual cases. Some examples are:

▶Gross error sensing—Since the solution to a control-signal calculation is repeated many times each minute or second, a single large error can be sensed by the computer program itself. Any change in a variable exceeding a given level may be automatically rejected and a reasonable average substituted.

▶Averaging—It is often necessary and desirable to average measurements before they are used for guidance or control.

▶Time sharing—to make economic use of a computing-controller, a time-sharing arrangement may be needed. Measurements, calculations, or even several complete processes may be handled intermittently by time-sharing.

▶Special programs—Many special problems can be solved by the computer program. For instance, when a valve goes to a limit and thus loses control, the computer can search for alternative ways to maintain control and can alarm if no alternative exists.

CHARACTERIZING THE PROCESS

No short-cut method exists for obtaining the process equations required for a computing-controller's program. A number of approaches have been developed, and a combination of several may be used, that balances theoretical, empirical, and experimental methods to obtain the best answer consistent with the economic justification and process information available. The following methods have been successful:

▶The analytical approach
▶Exploration of response surfaces
▶Linear multivariable systems
▶Statistical correlation

THE ANALYTICAL APPROACH

This is the best method, if it is possible and economical. A complete set of basic differential equations describes the system and characterizes static and dynamic performance at the same time. Only the system parameter values, to provide equation constants and boundary conditions, need be determined by experiment.

The difficulty of solving equations for many processes effectively discourages a complete hand calculation. Interactions, nonlinearities, and discontinuities set up a maze of computational difficulties, making manual manipulation of equations uneconomical if not impossible. Digital and analog computers, however, have made the job relatively straightforward, leaving characterization of the process in terms of its basic descriptive equations as the only stumbling

block. It is true, of course, that many processes are simply not understood, but there are still a great many that can be readily characterized by:

- The law of conservation of energy
- The law of conservation of matter
- The concepts of driving force and impedance

These laws are commonly known as energy balance, material balance, and equations of flow, heat transfer, etc. The approach stressed here is the simultaneous application of all the laws required by the problem, together with nonlinearities and discontinuities, no matter how complicated the set of equations becomes. It is the computer's task, whether in the design of a system or in its ultimate control, to handle these relationships which as a group cannot be comprehended or manipulated by a human being.

The application of these laws can be illustrated by a pipe-line reactor process, Figure 3. The big advantages of this type of process are its small capital investment, and high production with adequate quality. The control problem is formulated:

Process description

1. Material A is added to an excess of material *B* in a mixing nozzle to yield product *C*, by-product *D*, and heat.
2. Three zones provide: heat to start the reaction Zone I, cooling to control reaction rate Zone II, and cooling to suppress by-product formation Zone III.
3. Random process upsets: activity of material A; heat losses.
   Predictable upsets: changes in production rate.
   External inputs: production rate; cost of separating excess *B*; value of product and by-product.
   Product and process properties (not directly measurable): location and magnitude of hot-spot; molecular weight of final product.
   Measurement of state: pipe-line temperatures; by-product in effluent.
   Process controls: flow of A; flow of *B*; heat to Zone I; cooling to Zones II and III.
   Output data: continuous yield; by-product formation rates; cumulative production rates; exit composition by computation.

Basic data available: all physical constants and geometry, including the chemical kinetic coefficients for both the direct reaction and the side reaction.

The purpose of the analysis would be to determine:

(1) Control equations to provide signals to the valves controlling reactant A, reactant *B*, preheat to Zone I, cooling to Zones II and III.

(2) Optimizing equations to achieve overall process efficiency independent of disturbances or production rate.

(3) Auxiliary calculations required for process accounting and operating guides.

Process model

The first step is to set up an analytical model of the process. The important factors are the temperature and composition gradients down the reaction pipe, the reaction system dynamics, and heating-cooling system dynamics. All these factors are included in a set of partial differential equations, with time and distance along the pipe being the independent variables. It is customary to divide the spatial variable into finite differences to convert these equations to ordinary differential equations. The pipe is therefore divided into sections along its length and within each section all parameters and variables are assumed constant. An adequate number of sections for a particular problem depends on the steepness of the gradients. Experience indicates that in many cases a very few sections are adequate (between four and ten). The basic laws of heat transfer, mass transfer, and chemical kinetics may be applied for each section, Figure 4.

WALL (axial symmetry assumed)

Heat balance

Heat rate in − heat rate out = rate of heat accumulation

$$Q_o+Q_1+Q_w-Q_2=C_w\frac{dT_w}{dt} \tag{1}$$

Q_o = to be defined by control function, Btu/min
$Q_1 = K(T_{w1}-T_w)$, Btu/min
$Q_2 = K(T_w-T_{w2})$, Btu/min
$Q_w = 1/R_F(T-T_w)$, Btu/min
K = overall heat transfer coefficient between section centers, Btu/min-deg F
T = temperatures of wall sections and liquid, deg F
R_F = heat transfer film coefficient at wall, deg F/Btu
C_w = heat capacity of total section wall, Btu/deg F
t = time, min.

LIQUID (axial symmetry assumed)

Heat balance

Heat rate in − heat rate out + heat of reaction = rate of heat accumulation

$$Wc_p(T_1-T_o)-Wc_p(T-T_o)-Q_w+Q_R=C_L\frac{dT}{dt} \tag{2}$$

W = total liquid flow, lb/min
c_p = average specific heat, Btu/lb-deg F
T_o = reference temperature (disappears from equation)
$Q_R = h_cR_c+h_dR_d$, Btu/min
$h_{c,d}$ = heats of reaction $A\rightarrow C$ and $C\rightarrow D$, Btu/lb
C_L = heat capacity of total section liquid, Btu/deg F
R_c, R_d = reaction rates of formation C and D, lb/min [both are $f(T)$]

Material balances

Rate A in − rate A − rate A reacted = rate A

$$WA_1-WA-k_1R_c=C_M\frac{dA}{dt} \tag{3}$$

Rate C in − rate C out + rate C formed − rate C reacted = rate C accumulated.

$$WC_1-WC+R_c-k_2R_d=C_M\frac{dC}{dt} \tag{4}$$

Rate D in − rate D out + rate D formed = rate D accumulated.

$$WD_1-WD+R_d=C_M\frac{dD}{dt} \tag{5}$$

A, C, D = fractional concentrations of materials A, C, and D
k_1 = constant relating reaction of A to formation of C (product)
k_2 = constant relating reaction of C to formation of D (by-product)
C_M = total material hold-up in the section, lb
$R_c = K_cAe^{-M_c/T}$, lb/min = reaction rate of C
$R_d = K_dC^{1/3}e^{-M_d/T}$, lb/min
$K_{c,d}$ = reaction constants, lb/min

Note: $e^{-M/T}$ is a reaction rate of the Arrhenius form. Others may be encountered.

ANALYZING A PIPE-LINE REACTION

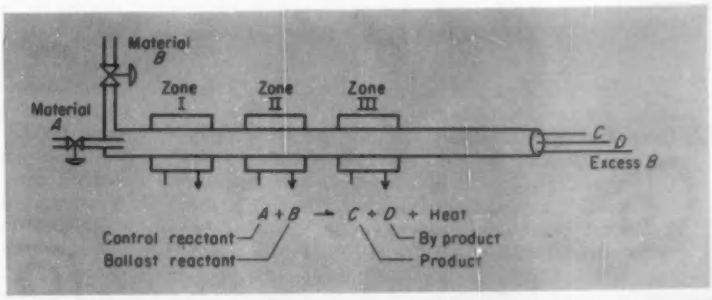


FIG. 3. A pipe-line chemical reaction is one of the newer processes that needs computing-control to handle its complex relationships.

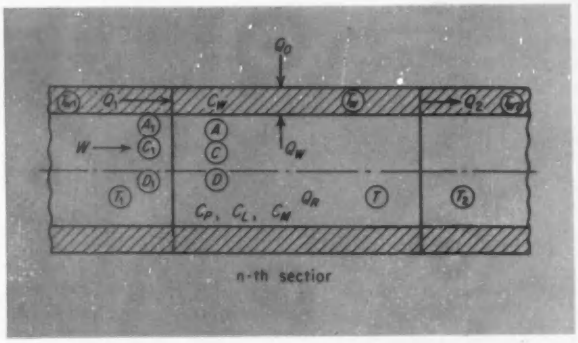


FIG. 4. The first step in the computing-control of many processes is to separate the process into finite sections, analyze each section from basic laws of nature, and program the mathematical representation into an electronic simulator. Control information gleaned from the simulation study determines how much of the complete model must be reproduced in the computing-controller.

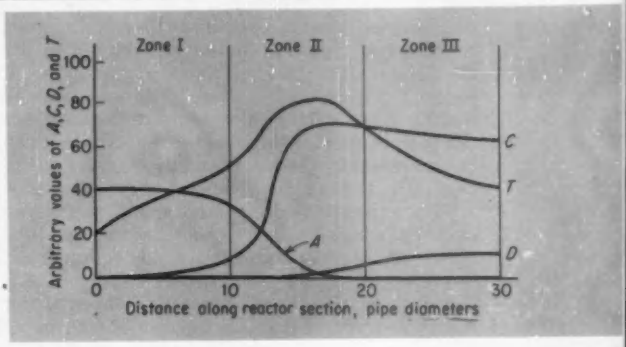


FIG. 5. Simulation determines static gradients of process variables along the length of the reactor section of the pipe.

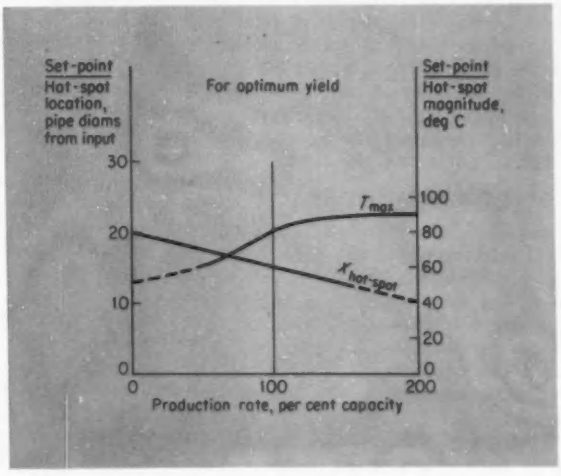


FIG. 6. With a complete mathematical model, the simulated system can show the relationships between production rate and maximum temperature location and maximum temperature for optimum yield.

Equations 1 through 5 represent the complete dynamic behavior within each section so long as there is ideal mixing. Deviations from ideal can be handled empirically. The values of all constants are determined from geometry, basic physical constants, and chemical kinetic data. These equations, one set for each section, are then programmed for solution on an electronic simulator, usually analog, with flow-sheet values for input composition, flow rates, temperatures, and external heat flow to or from each zone. All static gradients, as well as the dynamic response of the complete system to any combination of input, may be determined from the simulated model. The gradients will take a form such as shown in Figure 5.

The simulated model permits investigation of various control schemes. According to basic data, the measurements that can be used are material flows, coolant- and heating-medium flows, temperatures anywhere in the system, and concentration of by-product D in the effluent by continuous ultraviolet analysis. In the investigation of alternative controls, instrumentation dynamics must be included.

It can be determined by simulation that all the proposed manipulated variables have an effect on all the process gradients; therefore, a multivariable controller in which the signal to each valve is computed from a combination of several measurements will be used to get more precise and faster control (see later section on linear multivariable systems).

The basic objectives will be to sense the location and the magnitude of the temperature hot-spot and to control these variables by changing input composition, preheat, and reaction-zone cooling. By-product concentration, as sensed after a sampling lag, will be used to control the Zone III cooling to minimize the side reaction.

By the method described in "Computing-control Applied to a Sintering Process", page 130, the continuous location and magnitude of the hot spot may be computed from discrete thermocouple readings.

Completely rational means are now available to determine (by multivariable theory) and test (by simulation) the control signals required for each process valve in terms of the process measurements.

Presumably the control equations would be chosen to provide an optimum efficiency (or yield) under flow-sheet conditions. Operation at different rates would usually give a lower yield value. Having the complete mathematical model of the process and its control system, conditions different from standard can be tried on the simulation to find the relation, for example, between production rate (W lb/min throughput) and the location and magnitude of the hot-spot for maximum yield. The equations representing these relationships (or the empirical curves) can then be used in the computing-controller to adjust the set-points of these two operating guides in accordance with throughput. Figure 6 shows the curves.

The complete mathematical model of the process could be included in the computing-controller to allow calculation of production rates, yield, and other criteria of performance. This might make it easier to deduce hot-spot location and magnitude. Investigation of the simulation model will uncover many simplifications relating measurable quantities to the desired production data. For example, a calculation of total heat generated, heat added, and heat taken away would give the total rate of materials C and D being formed. The analyzer measurement of concentration D and the flow measurement of throughput give the additional information for computing the rate of C formation alone. A further calculation gives yield.

EXPLORATION OF STATIC RESPONSE SURFACES

Often processes cannot be analyzed from basic laws —either the theoretical relationships between factors affecting a process are partly or completely unknown, or a basic analysis is less economical than other approaches. When a plant is already in existence and little process theory is available, an empirical approach may be best. The concepts described next are useful where steady-state relationships are desired for nonlinear systems.

The present disadvantages of the approach lie in its inability to handle dynamics (further development now in progress may remove this shortcoming) and in the lack of direct relationship between its empirically derived coefficients and the constants of physical process equipment. It involves both the design of efficient experiments and the statistical manipulation of experimental data.

Consider a process that has some output function (response) like yield, which is defined by several variables (factors) like temperature, pressure, concentration, etc. Mathematically, the response is:

$$R = f(T, P, a - - - -)$$

The problem is to find empirically the exact relationship between R and the variables and to find values of the variables that will optimize this response—if there is an optimum. Measurements on an operating process if properly taken can give such a relationship and such optimum values of variables. The usual procedure in investigating a process is as follows. All factors will be held constant except one, and that one will be manipulated to produce one maximum response. Next, a second factor will be varied alone, and so on until ranges of all pertinent factors have been covered, to produce the best maximum yield.

While quite commonplace, this one-at-a-time method can lead to seriously wrong answers. There is a better testing procedure to take its place: the methodical exploration of a response surface.

The concept of the response surface can be introduced by a set of optimizing yield curves, Figure 7. Here, if the pressure is held constant at P_a the yield varies only with temperature T_a and a maximum exists at T_{oa}. But the figure also shows that if pressure is changed to a new constant value then a new maximum occurs at a different value of T_o. (The values of the maxima could be different, although they are shown as the same here.) Thus, the optimum yield becomes a function of P and T.

A response function of two factors will in general form a contour like the rolling countryside. The problem is to find the location (conditions) of the mountain peaks (optimum yields).

Figure 8 shows typical yield contours that can be obtained by replotting the family of curves in Figure 7. Now the axis representing yield is perpendicular to the page and combinations of x_1 (temperature) and x_2 (pressure) that produce the same yield are connected by a contour line. This is the type of system that is considered in the one-at-atime experiment and which tacitly assumes that $\partial f/\partial x_1$ is independent of x_2 and $\partial f/\partial x_2$ is independent of x_1. Starting at any point P, x_1 is varied to maximize R and then x_2 is varied. This procedure is carried out repeatedly until the true maximum is reached. The number of trials needed to reach the true maximum increases rapidly when the contours are attenuated and diagonally oriented as shown in Figure 9. Attenuation and diagonal orientation indicates interaction between variables.

Figure 10 represents the case of a response function having a stationary ridge. Starting at P and changing x_1 gives a true maximum at Q. But this set of conditions is not the only one giving this maximum and operation at Q′ might represent a cheaper and more convenient process.

The rising ridge shown in Figure 11 demonstrates the fallacy of the one-at-a-time method. Here, starting at P and varying x_1 gives a maximum at Q but variations in x_2 will not bring the process nearer to the true maximum. However, in Figures 10 and 11 the true maximum can be obtained by varying both factors simultaneously and ascending diagonally up the slope. The fact that the true maximum can be achieved in this manner means that a more fundamental variable, such as $W = x_1 x_2$ affects yield, Figure 12. (The reason for this is simple. Optima occur in nature as a function of specific physical factors. But convenient measurements, not necessarily the same as those in natural relationships, are often chosen for process measurements.)

Systematic methods have been developed for exploring systems of many factors with the least number of experiments. The procedure is complex, but the concept is not difficult. A two-step strategy is used:

1. The contour is traversed experimentally by following the path of steepest ascent. Appropriate n-dimensional curves are statistically fitted to experimental data to define the local slope.

EXPLORING RESPONSE SURFACES

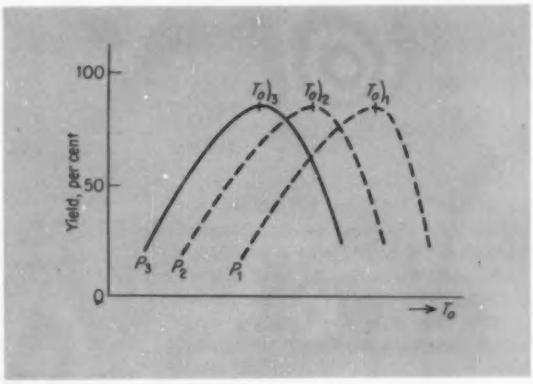


FIG. 7. Family of curves shows that yield is a function of both pressure and temperature.

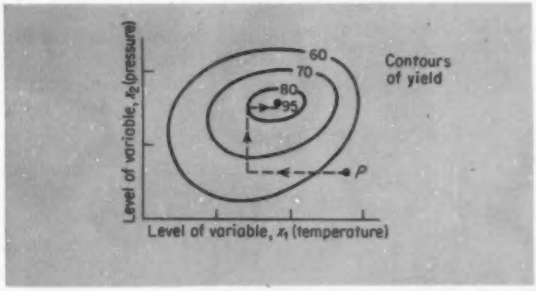


FIG. 8. Contours of yield for a two-factor process such as the one in Figure 7.

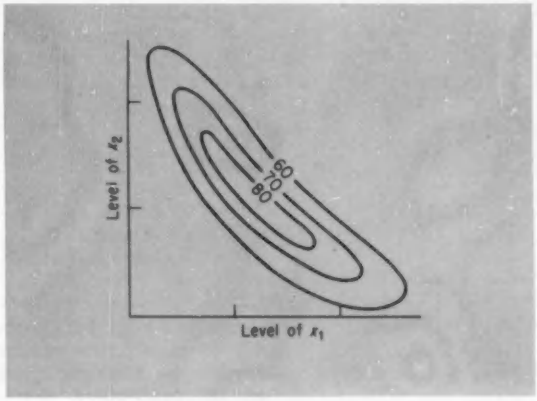


FIG. 9. Attenuated and diagonally oriented contours indicate interaction between factors.

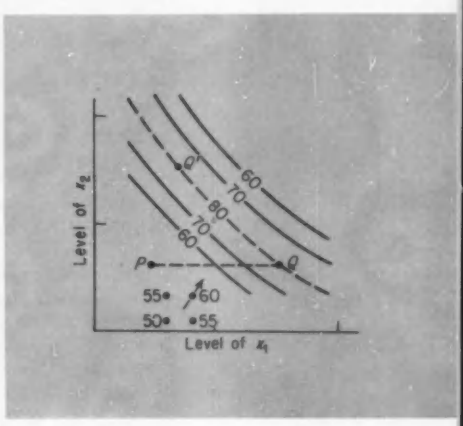


FIG. 10. Attenuated contours with a stationary ridge do not assure reaching the most efficient maximum when changing one variable at a time.

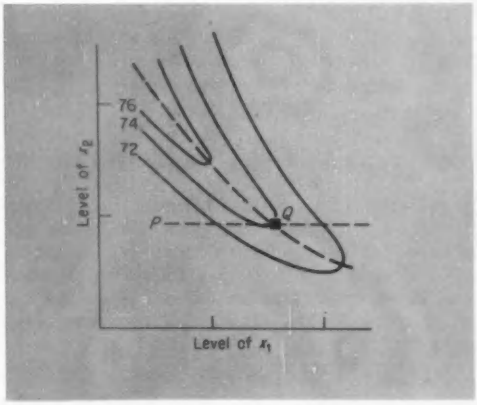
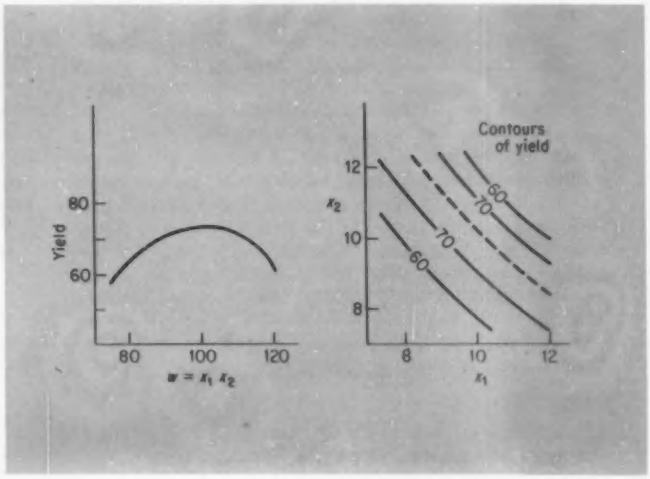


FIG. 11. One-at-a-time testing on contours with a rising ridge leads to wrong answers about the location of the true maximum, but ascending the slope diagonally by changing both variables simultaneously assures reaching the true maximum.

FIG. 12. A ridge system is generated because of interaction between two measured, but not necessarily physically significant, variables.



2. As the path approaches the peak where:

$$\frac{\partial f}{\partial x_1} = \frac{\partial f}{\partial x_2} = 0$$

a nonlinear curve is fitted to data in this region to get an approximate expression for the contour.

The expressions obtained in this manner are the equations needed for optimizing a process. And they are the same (to a reasonable approximation) that would be obtained if it was possible to analyze the process. They lack only the dynamic factors for a stable control system that restores the operating point to optimum when a disturbance has driven it off. Stability information can in many instances be inferred from other process considerations.

Although a theoretical understanding of the process mechanism is not essential to this basically empirical method, theoretical information can reduce the number of constants to be evaluated.

MULTIVARIABLE SYSTEMS

This section describes a synthesis technique for characterizing multivariable linear systems. Algebraic and equivalent open-loop methods are used to effect stability and noninteraction.

Figure 13 shows the common linear model of processes frequently used for single-loop control systems. Box E includes the process itself, servos, and instruments—that is, all behavior from a manipulated variable x to a measured variable y. Variable Z represents the behavior of output y when the manipulated variable is fixed. The actual disturbances and inputs do not necessarily enter the system at the point shown in Figure 13, but because of assumed linearity the model is quite general.

The process of Figure 13 can be represented by:

$$y = Z + E \cdot x \tag{1}$$

For multivariable processes Equation 1 still holds, where E is now a matrix of operators and x, y, and Z are now column matrices of variables. The expanded form of Equation 1 is:

$$y_j = Z_j + \Sigma_k E_{jk} \cdot x_k \tag{2}$$

which suggests a compact block diagram, Figure 14 suitable for multivariable processes. Each operator E_{jk} represents a process in which each manipulated variable separately affects every output. A comparison of Equation 2 with Figure 14 shows that each E_{jk} operates on the input in its column x_k, and each y_j is equal to the sum of the operational products in its row and its total effective disturbances Z_j.

The general multivariable system is shown in Figure 15A. The controller matrix representation is similar to that of the process matrix. The measured variables y are its inputs, the manipulated variables x are its outputs, and the errors e are the system variables of interest on which performance criteria are placed. For generality, the error variables are shown generated in Figure 15B by a matrix H and disturbances W in a manner similar to the generations of y. These errors may include the variables being controlled (or related variables), other system variables to be limited or constrained, and variables being constrained to account for nonlinearities. Controller action C, for which the measured variables are chosen as inputs, minimizes or constrains these errors.

Specification of controller C involves a choice only among those modes which stabilize the closed loop of Figure 15A. This step is simplified by the use of an equivalent open-loop system, Figure 16. It can be shown that if:

$$C = F(1+EF)^{-1} \tag{3}$$

there is a one-to-one correspondence between the systems of Figures 15 and 16. Furthermore, the criteria of stability of the closed-loop system is merely that each F_{jk} be a stable structure. Thus, the system can be more easily designed in terms of Figure 16, with the proviso only that each F_{jk} be stable. The controller C is then determined by Equation 3.

The equivalent open-loop concept allows free choice of a stable control mode. The responses of pertinent system variables are:

$$e = W + (HF) \cdot Z \tag{4a}$$

$$y = (1+EF) \cdot Z \tag{4b}$$

The responses are determined by the operators HF and EF, which are limited only by the conditions that all elements of F be stable. For example, if E is a square matrix, $R = -EF$, then:

$$F = -E^{-1}R = \text{a stable structure} \tag{5a}$$

$$C = -E^{-1}R(1-R)^{-1} \tag{5b}$$

Any response R can be chosen which satisfies Equation 5a. The basic limitation on the response arises from the nonminimum-phase nature of the determinant of E.

Noninteraction

Controlling more than one variable generally means an interaction among the variables controlled. A new setting for one variable may cause, during the transient state, changes in other variables. If these other variables are operating at or near a maximum point, the interaction may cause serious damage to the process. It would therefore be desirable that each new setting of a controlled variable effect only the variable being set, thus eliminating interaction.

Consider the following specification for noninteraction: any one error y_j is to affect only its corresponding output variable. This is identical to saying that any one Z_j is to affect only its corresponding variables y_j. This condition leads to:

$$(EF)_{vj} = (EC)_{vj} = 0 \qquad \text{for all } v \neq j \tag{6}$$

If E is a square matrix then:

$$\frac{F_{sj}}{F_{jj}} = \frac{C_{sj}}{C_{jj}} = \frac{(E^{-1})_{sj}}{(E^{-1})_{jj}} \qquad \text{for all } s \tag{7}$$

which gives the required ratios between the elements of the jth column of C. The similar relations for F indicates that these relations for C can be maintained in a stable system. The remaining element of C in its jth column is set by criteria on the response of y_j to Z_j and stability. These conditions are given by:

$$F_{sj} = -(E^{-1})_{sj} R_{jj} = \text{a stable structure} \tag{8a}$$

$$C_{sj} = -(E^{-1})_{sj} \frac{R_{jj}}{1-R_{jj}} \text{ for all } s \tag{8b}$$

For complete noninteraction—separating the interacting multi-loop system into isolated loops each of which can be treated as a single-variable system—

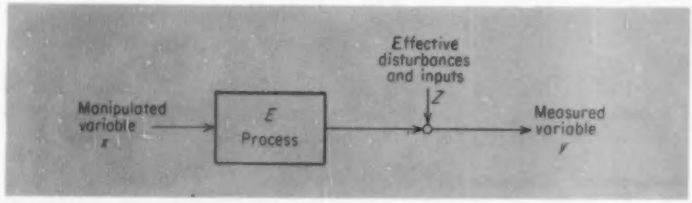


FIG. 13. General block diagram of single-variable linear process.

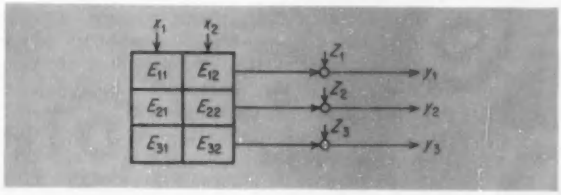
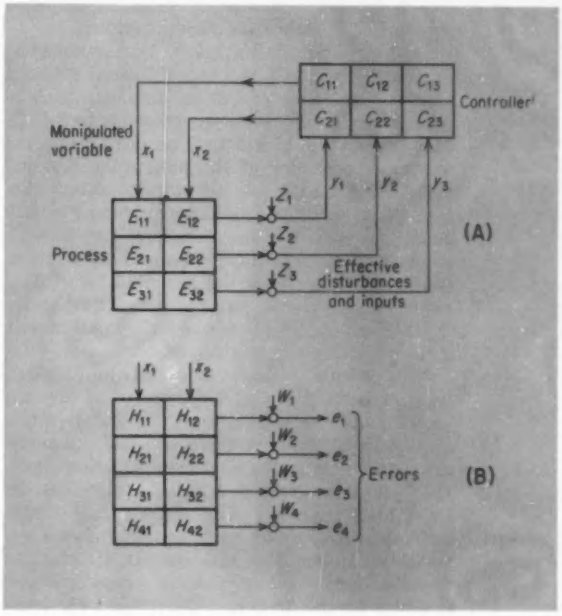


FIG. 14. Linear model for multivariable processes.



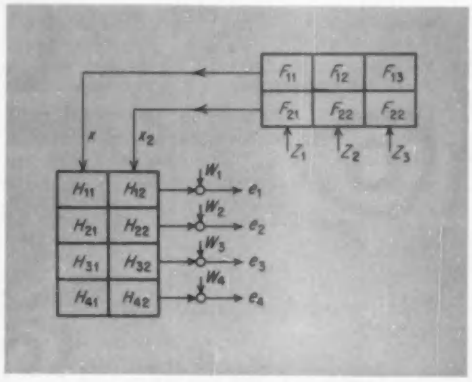
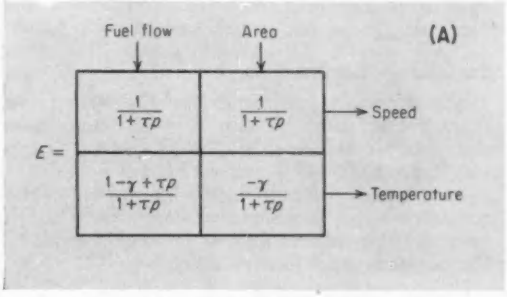


FIG. 16. Equivalent open-loop system for that in Figure 15 aids systems analysis.

FIG. 15. General linear multivariable controlled system.



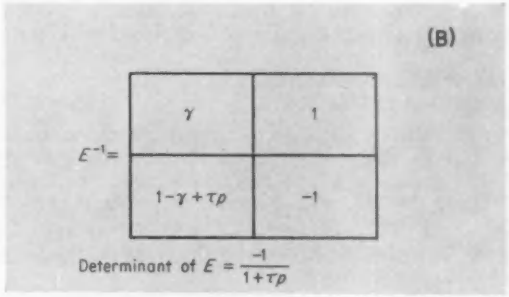


FIG. 17. Process block diagram matrices for turbojet engine. Matrix E describes mathematical model of the engine, while the inverse matrix E^{-1} is used to find the transfer functions of the stable controller.

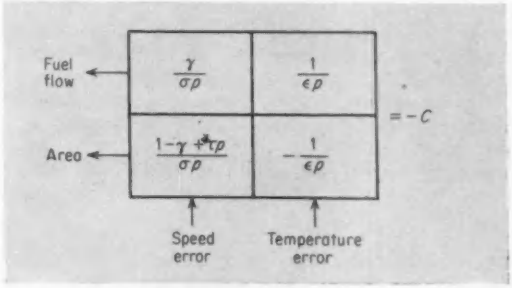


FIG. 18. Controller block diagram matrix for the turbojet engine.

EF and EC are diagonal matrices and Equations 7 and 8 hold for all j. Stability and controllability of each variable is thus greatly simplified.

Noninteraction example

Control of rotor speed and turbine temperature of a turbojet engine requires the manipulation of engine-fuel flow and jet-nozzle area. The differential equations obtained by linearizing the general quasi-static functions relating rotor torque, rotor speed, turbine temperature, engine-fuel flow, and jet-nozzle area are:

$$N+\tau\dot{N}=bw_f+aA \tag{10a}$$

$$T=cw_f-eN \tag{10b}$$

where:
a, b, c, e = constants
N = engine speed
w_f = engine fuel flow
$\dot{N}$ = engine acceleration
A = jet nozzle area
T = engine temperature
τ = engine time constant

Placing these equations in operational form and redefining units yields engine matrix E of Figure 17A, where $\gamma = be/c$. The inverse engine matrix E^{-1} is shown in Figure 17B, from which, for noninteraction:

$$\frac{C_{21}}{C_{11}}=\frac{1-\gamma+\tau_p}{\gamma} \tag{11a}$$

$$\frac{C_{12}}{C_{22}}=-1 \tag{11b}$$

The response, from Equation 8a, is subject to these restrictions:

$$\left.\begin{aligned} F_{11}&=-\gamma R_{11}\\ F_{21}&=-(1-\gamma+\tau_p)R_{11}\\ F_{22}&=-F_{12}=R_{22}\end{aligned}\right\}\ \text{all stable} \tag{12}$$

The equation for C is

$$C_{11}=\frac{-\gamma R_{11}}{1-R_{11}} \qquad C_{21}=\frac{-(1-\gamma+\tau_p)R_{11}}{1-R_{11}}$$

$$C_{22}=-C_{12}=\frac{R_{22}}{1-R_{22}} \tag{13}$$

For $R_{11}=\dfrac{1}{1+\sigma p}$ and $R_{22}=\dfrac{1}{1+\epsilon p}$ (where σ is of order τ)

the control matrix is shown on Figure 18. All four controllers are used, the forms being of integral and proportional-plus-integral types. In this way, speed- and temperature-error signals do not affect each other.

STATISTICAL CORRELATION OF OPERATING RECORDS

A number of methods are available for obtaining the transfer functions of linear system from system tests. One uses a special-purpose computer to reduce plant test data and thus get direct frequency response plots. At least one controller has been proposed which periodically determines the process transfer functions during operation.

Another approach involves the statistical correlation of ordinary plant operating records. Any operating process, whether on automatic or manual control, is being continuously "tested" but the results are usually ignored. Every input to a process is constantly changing due to minor unavoidable disturbances. And the smallest changes will affect the outputs in a way that is characteristic of the process. By properly correlating output variations with these random observed inputs, the process characteristics (transfer functions) can be deduced. This is similar to other techniques like frequency, step, or impulse response tests, except that the inputs are not predictable, but must be described by statistical means. The method is limited to cases where the statistical nature of the inputs does not vary, or does so slowly, with time.

If a system is determinate, whatever methods are used to describe it should be equivalent. Figure 19 shows two equivalent ways of looking at a dynamic system. One, the frequency response approach, depends on the separation of a continuous function of time (basically periodic over some range) by Fourier analysis into a sum of sinusoids. The linear system acts on these sinusoids according to its descriptive frequency response to produce outputs whose summation becomes the system output.

Just as valid is the other, the impulse response approach, in which the input time function is considered as a series of pulses, each occurring at fixed time intervals. The output response to pulses shows that neither the pulses that occurred some time ago nor those occurring at the present interval will have much effect on the present output. But it also shows that pulses that occurred at a particular past interval associated with the major process lag will have the greatest effect at present. Thus there is a weighing-function which relates the contribution to the output made by each input pulse as a function of the time it occurred. These two approaches can be rigorously demonstrated to be equivalent.

This theory permits a useful transformation of plant records and their interpretation by auto- and cross-correlation functions. All needed information in the input time function can be compactly summarized in an auto-correlation function that essentially describes how a real input deviates from an ideal unit impulse. The output time function is similarly summarized by a cross-correlation function which describes the real output to this nonideal impulse input. The process characteristic corresponding to the frequency response now becomes a weighting function plotted against time interval. Figure 20 shows this transformation and typical correlation and weighting functions. The same correlation functions will result from any section of the time functions so long as sufficient data is included.

Correlation functions

The formation of correlation functions is conceptually easy although it may be laborious. Analog and digital computers can readily perform the calculations. Essentially, auto-correlation is comparing a time function (here, input) with itself, whereas cross-correlation is comparing one function with another (here, output with input). Mathematically the two correlation functions are:

$$\phi_{mm}(\tau)=\overline{m(t)\ m(t+\tau)}$$

$$\phi_{mc}(\tau)=\overline{m(t)\ c(t+\tau)}$$

where ϕ_{mm} = auto-correlation function
ϕ_{mc} = cross-correlation function
$m(t)$ = input time function
$c(t)$ = output time function
τ = time interval

The bars indicate average value of the product over a suitable time segment.

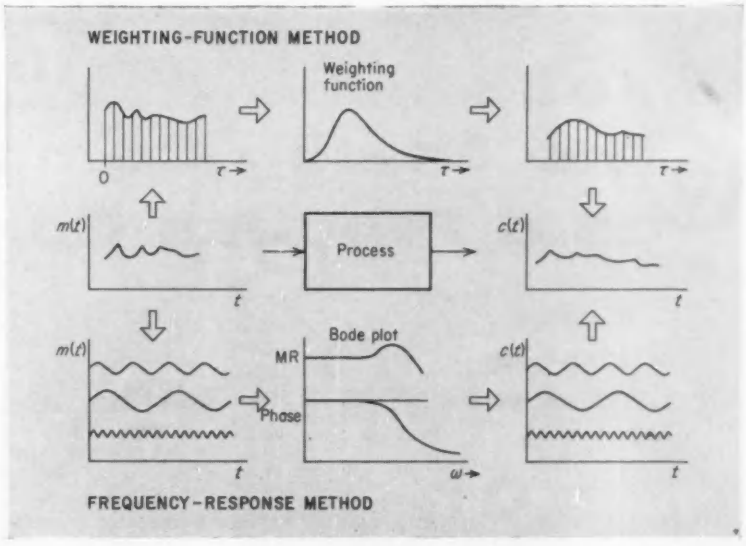


FIG. 19. Two equivalent ways of looking at a process are its frequency response and weighting function. They can be demonstrated to be equivalent by use of Fourier and Laplace transforms.

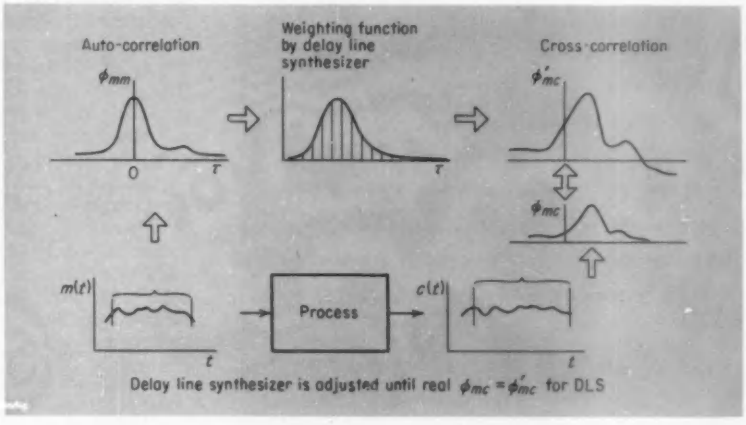


FIG. 20. Determining the weighting function from a delay-line synthesizer characterizes the process as a transfer function by test or calculation.

The usual procedure has been first, to form ϕ_{mm} and ϕ_{mc} from plant records with a special-purpose computer, then to introduce ϕ_{mm} as the input to a special analog device called a delay-line synthesizer (*DLS*). The *DLS* delays the input by several discrete increments of time $n(\tau)$. Each delayed signal is then multiplied by an adjustable factor h and all are summed to produce an output. The *DLS* is merely an electronic model of the weighting function and the h's can be adjusted to describe any system. When ϕ_{mm} is fed periodically into an unadjusted *DLS* a ϕ_{mc} automatically results which can be compared with the known ϕ_{mc} of the process and the error displayed on a scope. Adjustment of the various values of h are largely noninteracting and can be made to null the error signal. The weighting function in the *DLS* achieved by this method is that of the desired process characteristic, which may be determined in transfer-function form by calculation using the values of h or by experimental frequency response tests on the *DLS*.

This method not only discriminates against system noise, but unlike other approaches, allows closed-loop data to be analyzed with only a minor penalty for loop-circulated noise. Its operational disadvantages can be overcome with improved equipment; and its limitations to dynamic responses (small changes) and to linear systems are being investigated actively.

The most interesting thing about this method is that the operations required, such as sampling, large number of simple calculations, and introduction of pure delay, are ideally suited to digital computers. The possibility of continuously improving the operation of a controller with information gained on each transient it undergoes offers a real challenge.

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The Analog Computer as a Process Controller

D. W. RUSSELL

W. K. McGREGOR

L. F. BURNS, Aro, Inc.

THE GIST: The analog computer comes full circle in its new role as a controller. Originally designed for fire control work, analog computing devices evolved into the widely used electronic differential analyzer—the familiar general-purpose analog computer. The standard industrial pneumatic (fixed-function) controller and the ratioing and summing "relays" used with it for cascade control perform elementary analog computations. New electronic process controllers that have recently appeared more closely resemble simple electronic differential analyzers. They share many of the advantages of the electronic analog computers, but are limited in flexibility. As a controller, the analog computer often works best as a hybrid that uses the available components of many computers. The advantages and disadvantages of the various possibilities are discussed here by men who have long practical experience with all of them. A wind tunnel surge control problem illustrates the approach they have developed.

The continuous nature of most physical processes would indicate that they can best be handled by the continuous or analog controller. The other processes —those that exhibit distinct nonlinearities or discontinuities—would seem to fall naturally to the digital controller, which will also undoubtedly prove most useful where it is necessary to control several processes with a single controller on a time-shared basis.

Looked at dynamically, the response of the analog computer represents the limit attainable for very high sampling rates in a digital system, indicating a very fast (expensive) digital computer. And as far as availability is concerned, there is the simple fact that many kinds of computers and computing building blocks of the analog type are commercially on hand. There are relatively few digital building blocks, even including the analog-to-digital and the digital-to-analog converters, that are necessary for a digital computer to work with a continuous (analog) process.

Another factor in favor of analog computers is cost. For example, industrial analog process controllers with adjustable proportional, derivative, and integral action are available for as little as $470. Operational amplifiers used in electronic differential analyzers, with their automatic stabilization units and power supplies prorated, cost about $200 each.

Very important, too, is the compatibility of analog computers with available measurement transducers and control actuators, including electro-pneumatic, electro-hydraulic, and electrical ones.

Choosing the analog computer

The control system designer can either purchase commercially available equipment or design his own. The authors are strong advocates of purchasing; they believe that the design of components should not be undertaken unless space, weight, shape, or special environmental conditions, etc., make it necessary.

Commercially available analog computers applied as controllers divide into three classifications: general-purpose computers, fixed-function industrial controllers, and hybrid computers.

General-purpose computers—Electronic differential analyzers such as Berkeley's EASE, Electronic Associates' PACE, Reeves Instrument's REAC, and Goodyear Aircraft's GEDA are general-purpose computers (GEDA is pictured in Figure 1). These computers generally have a large number of operational amplifiers, a patch panel, and some non-linear components. They provide the maximum in flexibility, and use high-gain operational amplifiers for computational accuracy. Their components have frequency responses much higher than most industrial processes.

Such computers require highly skilled operators because of the complexity of adjustments and patching. They are best adapted for laboratory use; that is, control of experimental or pilot processes where

the process or the mode of control changes frequently.

Fixed-function controllers–Special electronic analogs are available that were designed especially for industrial control, such as the controllers made by Manning, Maxwell & Moore; American Electronic Systems; and Swartwout. These have older, pneumatic analog counterparts (those made by Bristol, Foxboro, Leeds & Northrup, Minneapolis-Honeywell, and Taylor, for example). Special-purpose mechanical and hydraulic analogs have also been built in large numbers for control, but, in general, these are not available commercially. The statements of this article are limited to the electronic variety.

The industrial controller has been integrated with associated sensors, set-point devices, and power-amplifying equipment to form a complete control system supplied by a single manufacturer. For this reason very little engineering is required by the user to install and check out the system. But it is limited in what computations can be made and by its range of adjustments. At present its frequency response, because it uses electromechanical devices, is much lower than that of general-purpose computers.

Industrial controllers are the least expensive overall, however, and should be applied whenever possible. They are used in the Engine Test Facility at Tullahoma, Tenn., to control the pressures of the fuels being supplied to turbojet and ram-jet engines undergoing altitude flight simulation tests.

Hybrid analog computers–Control computers can be put together from the building blocks of general-purpose computers, and housed in a custom console with a patch board designed for the particular application. In the resulting hybrid computer (all necessary operational amplifiers, stabilizers, power supplies, function fitters, etc., purchased separately) there is both the flexibility needed for the application and a minimum of adustments for operational simplicity. Components are patched for a specific computation, which greatly increases reliability. Transducers, set-point devices, and the power amplifying equipment are selected to fit the particular system involved.

This approach to analog computing control is ideal for the transition from a block diagram to actual control hardware. More engineering is required than for the standard industrial controller, but the result is a control system exactly tailored to the process. By making use of reliable off-the-shelf equipment, much debugging is by-passed. This emphasizes system design rather than component design.

Since the equipment is basically modular, the controller can be modified or expanded very simply. This is useful where the process analysis is not exact or future plant expansions are planned.

Another advantage of this approach is that it saves components already in use. In converting a manual flow-control process to automatic operation, for example, all that is necessary is that the proper servo-valve or converter be selected to match the operational amplifiers to the valve actuators to be salvaged.

Controller functions

An electronic analog computer can be used in two ways for process control. The first of these is the so-called two-time-scale method. The second is as a more conventional real-time analog controller.

In the two-time scale method proposed by Ziebolz and Paynter in 1953[1], the process and the conventional controller are simulated on an analog computer at a very high speed compared to real time. The input and output of the real process are sampled and entered into the high-speed simulator, together with all other variable factors that can disturb the process. Using this sampled data as the initial condition, the high-speed (simulated) controller proceeds to control the simulated process for a simulated time (shorter than the sampling interval). The output of the simulated process at the end of the simulated time is compared with the set-point and used to start correcting the feedback signal of the real process much earlier than would be possible in a conventional feedback control system.

For example, the effects of a drift in a disturbing parameter (a heat exchanger temperature, perhaps) may not be felt at the output of the process for many minutes due to transportation lags in the process. A conventional controller can take no action to correct this disturbance until the disturbance is felt at the output, so that the disturbance is essentially uncontrolled for this period. In the two-time-scale system, the effect of this disturbance is "felt" in the simulated system less than one sample time later, which can easily be a tenth of a second or less. Thus, control action can be taken at the input to the real process practically immediately.

(For application of the two-time-scale method in analog systems, see "Optimizing Control of a Chemical Process" by Eckman and Lefkowitz, p. 197; for

FIG. 1. A general-purpose analog computer, Goodyear Aircraft's GEDA.

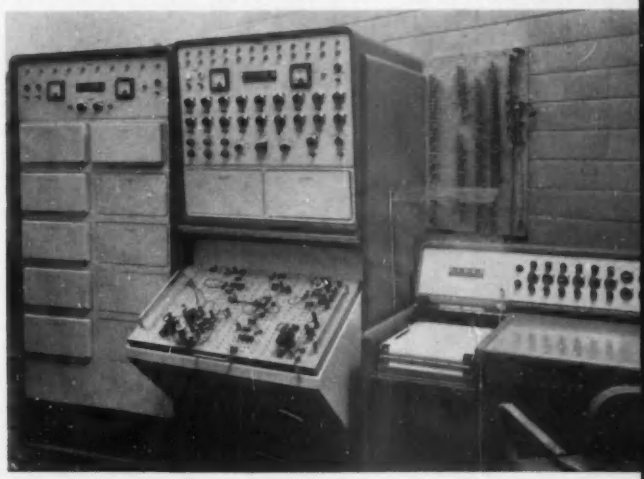
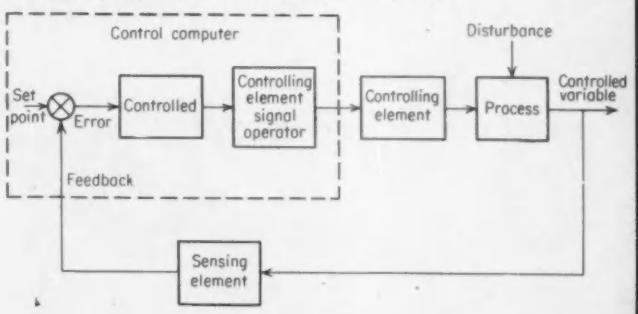


FIG. 2. Block diagram of typical process-control system.



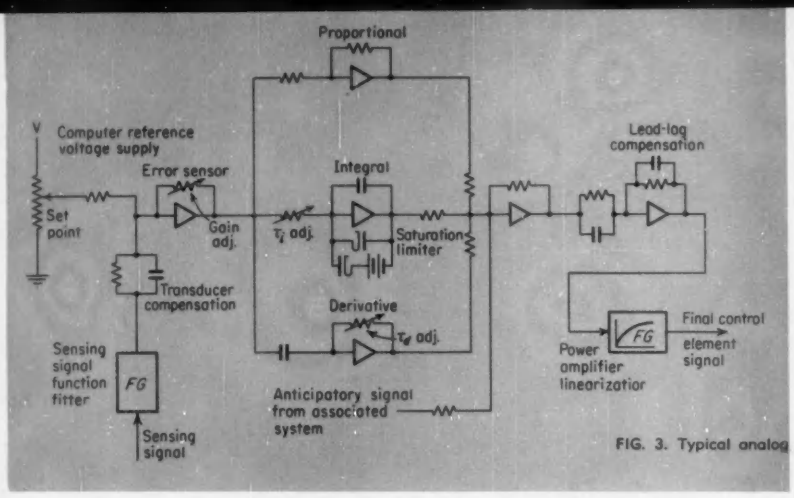


FIG. 3. Typical analog control computer circuit diagram.

its application in digital systems, see the feed forward methods used in "The Digital Computer as a Process Controller" by Tierney, et al., p. 166.–Ed.) This article shall deal fully only with the advantages and problems of the second approach mentioned above: applying the highly useful techniques of electronic analog computer design to the design of more conventional systems that operate in real time[3].

In this approach, the analog must perform all the functions from the feedback transducer output to the power amplifying element input, as illustrated by Figure 2, and thus needs an analog voltage signal from the feedback, and a power amplifying element which will accept an analog voltage as its input. In the ordinary functions of process control, pressure or temperature measurement and control valve actuation, such analog voltage signals are common.

The ordinary functions of any process controller are handled perfectly by dc operational amplifiers. Generating an error signal by subtraction of the feedback from the set-point is done simply by using an operational amplifier as a summer. The set-point comes from a potentiometer which is excited by the computer reference supply. Since the input impedance is high, the feedback can be from any transducer that produces a dc voltage or current. Thermocouples can be compensated by using the operational amplifier input impedance as a pure lead term.

Control system design

One of the deficiencies of most control analyses of complicated processes is the describing equations. If the process equations were exactly known, a control system could be synthesized to provide optimum performance. Ordinary industrial controls, pneumatic and stock electronic systems, largely ignore the synthesis and simply provide ranges of adjustment. The resulting performance is adequate in most applications. However, such systems cannot cope with extremely large ranges of adjustment and, in general, the adustment can be changed only by redesign of the component. The correction for errors or deficiencies in the analysis may be difficult with fixed-function controllers but is simply a matter of changing a resistor or capacitor with analog computer controllers. This advantage has rescued the authors on numerous occasions.

Most processes experience large changes in parameters (gains and time constants) with operating points; that is, their differential equations have nonconstant coefficients which are dependent upon operating points. If the process can always operate at fixed operating points with little deviation, then it is only necessary to provide sufficient ranges of adjustment. But if there are very large excursions, stability and dynamic response problems arise.

Electronic analog components are also available for correcting these difficulties. For example, nonlinear controlling elements may be linearized by biased-diode-type function generators; or some nonlinear operation, such as logarithm generating, may be made on the feedback signal. Also, a resistor in an operational amplifier assembly can be variable, as by instrument servos, or by the use of nonlinear resistance elements.

Usually, processes complicated enough to require a concentrated evaluation are separated into parts—each interacting to some extent with the others. If these interactions are appreciable and harmful, some means of interconnection is usually employed, the most common being anticipation fed to one system from another. An electronic analog components assembly, ideal for compensating this interaction, accom-

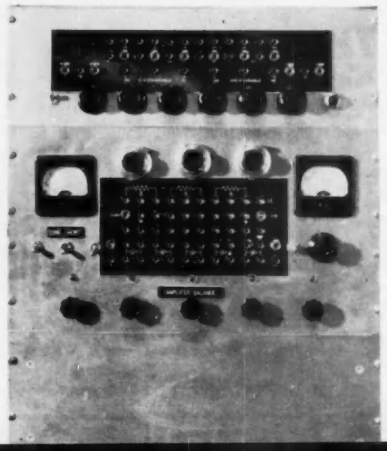


FIG. 4. Analog computer component assembly used as a portable experimental analog computer.

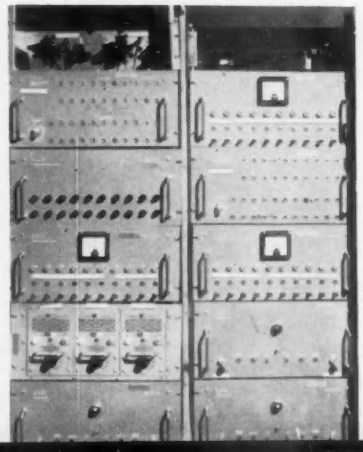


FIG. 5. Console housing analog computer components for pressure and temperature-control systems in jet engine test facility.

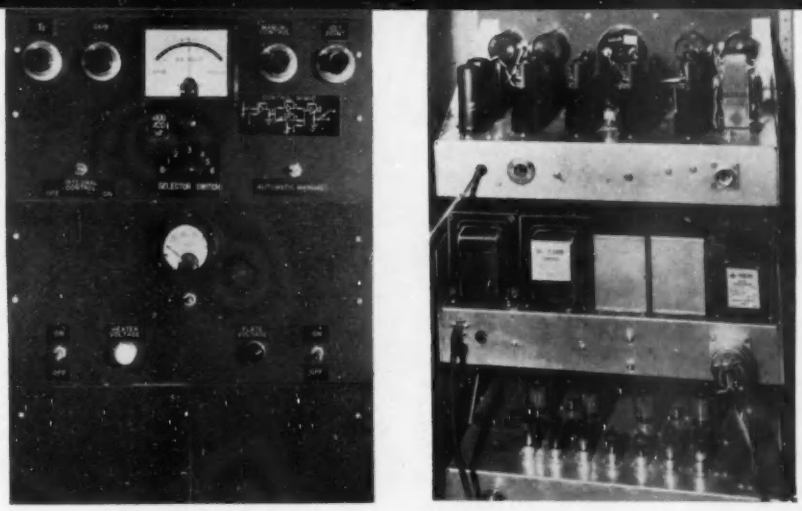


FIG. 6. Special-purpose computer for compressor-surge control (front and rear) uses Philbrick amplifiers in relatively fixed-function circuit.

plishes it simply by adding in a signal to an operational amplifier at the appropriate spot.

Many other functions easily accomplished with an analog computing controller are more difficult with other types. Among them: elimination of controller saturation and error limiting, both done with diodes. Several of the functions are illustrated in the analog control computer diagram of Figure 3.

Programming the computer

"Programming" general-purpose or hybrid analog computers is the process of patching or connecting their elements so that they perform the required mathematical operations. The general-purpose analog computer has a problem patchboard through which all the elements of the computer can be interconnected (Figure 1). A hybrid assembly such as an experimental control computer might have a specially constructed problem board for maximum flexibility. Figure 4, for example, shows a portable control computer used in experimental design of more permanent systems that has a special patchboard. Further restrictions might be made for permanently installed systems in which the computing resistors may have to be readily changed. This is illustrated by Figure 5, which is a pressure-control system for a jet-engine test facility controlled by a hybrid analog computer. The patching might also be permanent, as illustrated by Figure 6, which shows the mimic diagram of a compressor surge prevention control computer in which the components are permanently patched together and only test points are brought out.

In any case, the logical design of the patching on programming scheme should always provide the flexibility to correct possible errors, and the necessary test points for checking correct operation. The latter is a hidden advantage: it provides for easy trouble shooting, serves as an educator of the action of the system, and provides points for recording responses which are very difficult to obtain in ordinary systems.

SURGE CONTROL BY ANALOG COMPUTER

The following example will illustrate the application of a hybrid-analog computer as a process controller. The system chosen is a surge-prevention control system for a compressor in the Engine Test Facility at the Arnold Engineering Development Center, Tallahoma, Tenn.—largest of the aerodynamic-model and jet-engine test facilities operated by the Air Force, Air Research & Development Command. AEDC is operated for the Air Force by ARO, Inc., a subsidiary of Sverdrup & Parcel, Inc. Included in the example is a simplified analysis of the process and the synthesis of the control system. (For another way that computing control can be applied to wind tunnel surge control problems, see p. 134.—Ed.)

The electric-motor-driven, fixed-speed, three-stage centrifugal compressor used as an exhauster in the Engine Test Facility wind tunnel was originally equipped with an automatic surge control system. A new, more refined surge control system has been designed using analog computer components. It has been assembled and experimentally checked out, but as of this date has not been permanently installed. To avoid plant down time, as well as for economy, the existing valve and valve position system was used. The system performance was such that, when subjected to the severest possible disturbance, the machine surged only once.

The process

The compressor exhausts air from a large volume of ducting in order to simulate specified altitude conditions at the exhaust of a turbojet or ramjet engine. A schematic of the ducting, valves, compressors and drive unit is shown in Figure 7.

If the air flow is reduced below a certain minimum, the compressor blades undergo aerodynamic stall, which results in a reversal of flow. This can cause severe structural damage to the compressor and its drive mechanism. However, operation very close to this surge point is necessary for maximum performance. This requires a high-gain automatic control system.

The control system must sense the approach to stall condition and take corrective action to cause the control valve to maintain the air flow through the compressor higher than the surge value. Figure 8 is a characteristic curve for a centrifugal compressor discharging to atmosphere, showing the surge point.

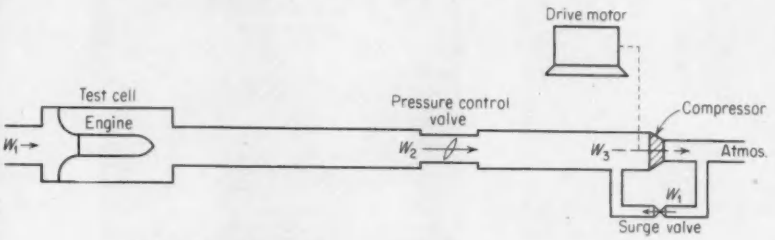


FIG. 7. Engine-test air flow system schematic.

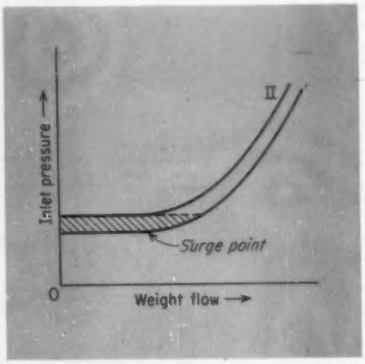


FIG. 8. Characteristic curve of a compressor used as an exhauster to atmosphere.

Two sensing variables are immediately apparent, inlet pressure and air flow. Pressure should be discarded because the slope is very gradual in the vicinity of surge and the gain would be low. This leaves air flow, which is measured with a total pressure sensor in the discharge line. Noise-free signals cannot be obtained here because the air flows in the surge region are very low, and the resulting spurious signals to the controller cause poor control system performance. The result here is a controller set-point corresponding to the lost performance shown in the shaded area of Figure 8. By installing a venturi in the discharge line and sensing the pressure drop across it as a measure of air flow, a signal with good signal/noise ratio can be obtained. The control system performance improves considerably, but the pressure drop across the venturi is a penalty in performance of the compressor as indicated by Curve II of Figure 8. This is the present method of control.

During recent experimental tests on the compressors, it was noted that the motor current is very nearly proportional to the air flow. It was also noted that when disturbances in air flow were introduced the lag between changes in inlet pressure and in motor current was negligible. A sensor was designed using a current transformer, a rectifier, and a filter to produce a dc signal proportional to load (motor current), and the signal/noise ratio was found to be high. It was thus concluded that a measure of motor current should be suitable as the sensing variable in a surge prevention control.

The analysis of the system is made using Figure 7 as a reference. Lower-case letters represent transformed perturbation of the variables and s denotes the Laplace variable.

The capacitive energy storage in volume V yields,

$$P=\frac{1}{Cs}(W_1+W_2-W_3) \qquad (1)$$

or

$$p=\frac{1}{Cs}(w_1+w_2-w_3)$$

where C is $\frac{V}{RT}$, V is the volume in cubic feet, and T is the temperature in degrees Rankine.

The weight flow through the surge valve is

$$W_1=K_1\frac{PA_1}{T}$$

(The valve is choked in the surge region and therefore can be represented by the choked orifice equation.) Dimensions of the equation are pressure in pounds per square foot, area in square feet, and temperature in degrees Rankine. K_1 is a constant equal to 0.533,

$$\text{or } w_1=k_1a \qquad (2)$$

The weight flow through the compressor at a constant temperature is

$$W_3=f(P)$$

$$\text{or } w_3=k_2p \qquad (3)$$

The relationship of weight flow to motor load can be expressed as

$$L=f(W_3)$$

$$\text{or } l=k_3w_3 \qquad (4)$$

The current in the secondary of the current transformer is proportional to load current — $I_t \propto L$

$$\text{Then } k=k_4l$$

$$\text{or } \quad k=k_3k_4w_3 \qquad (5)$$

Combining and simplifying Equations 1 through 5 results in

$$i=\frac{K_p}{\tau_p s+1}a_1 \qquad (6)$$

K_p is the gain of the uncontrolled system and is the product $k_1k_3k_4$. τ_p is the time constant of the uncontrolled system and is the ratio C/k_2.

The numerical values of the constants in Equation 6 can be calculated from the fundamental properties of the system in the surge region. The following values are typical:

Volume, $V=25{,}000$ ft³
Temperature, $T=550$ deg R
Weight flow at surge, $W_3=15$ lb/sec
Pressure at surge, $P=500$ to 700 lb/ft²
Load at surge, L = 2,100 to 2,300 Kw
Current in current transformer at surge, I_T = 1.5 amp

The transfer function, Equation 6, is numerically

$$i=\frac{0.86}{0.3\,s+1}a_1 \qquad (7)$$

The sensing element is illustrated at the lower left in Figure 9. Its response is much higher than that of the plant and the valve-positioning system and therefore its dynamics were not considered.

The valve-positioning system is the one already installed in the facility. It consists of an electro-pneumatic converter, a pneumatic actuator and a double-seat valve. The response of the entire valve system can be represented as a transfer function,

$$\frac{A_1}{E_v} = \frac{K_v}{\tau_v s + 1} = \frac{0.1}{0.5 s + 1} \qquad (8)$$

Control system synthesis

Operation at a stable point near the surge region requires porportional-plus-integral controller function. The gain which must be provided in the controller for stabilization can be established from the open-loop transfer function. Figure 2 is a block diagram of the system. The frequency-response curve was plotted and the controller gain calculated by establishing a gain of unity at the minus-135-deg phase-shift point. The integral action of the controller provides zero steady-state error. The rate at which the error is integrated out should be as rapid as possible without causing instability. A practice found to be satisfactory is to set the controller integral time constant to ten times the reciprocal of the frequency at which minus-135-deg phase-shift occurs.

Experimental setup

A breadboard controller of analog components should now be set up to determine the validity of the analysis and synthesis. A typical array of components for use in a breadboard model is shown in Figure 10. Each rack contains 10 operational amplifiers and stabilizers, potentiometers for setting coefficients or for use as setpoint devices, capacitors, diodes for use as limiters, function generators, a patch board, a voltmeter and the necessary power supplies.

The circuit (Figure 9) which represents the controller is patched into the problem board of the computer shown in Figure 10 for the experimental work.

Final design

The results of the experimental setup, operational procedure, availability of space, etc., determine the final control-system design. The results of the experimental system test, which will have fixed the gain, or range of the gain, time constant or its range, and the polarity inside the loop, dictate the number of amplifiers needed, the requirements for adjusting gain and integral time constants, and the value of the passive elements to be used.

The operational procedure will determine the need for a manual-automatic transfer switch, monitoring signals within the system, manual set-point devices, and any other elements to make the system compatible with similar systems in the same plant. The final stage of design for this application is a compact fitting of the circuit of Figure 9 into the package of Figure 6.

Conclusions

The choice of a controller for a system such as the one described here depends on several things. The prime one of course, is response of the system or of the power amplifying element. Another one, equally important, is the proportion of cost to benefits. A third is the established operational procedure in the plant, since a control system that is too complicated for the average operator can be worse than none. Reliability and ease of maintenance or repair complete the controller considerations.

Analog computer components are so designed that their frequency response is much higher than needed for this application, but this is not reflected in the cost. Stabilization by choppers or commutators raises the price per unit amplifier only slightly.

Analog computer components that produce an error signal and perform the computation of the controlling function provide low cost, reliable control of compressor surge. The reliability of the components is exceptional, and a spare amplifier is provided for malfunctions. The spare adds very little to the cost of the system. All components are easy to maintain and service and with proper care should give relatively trouble-free service.

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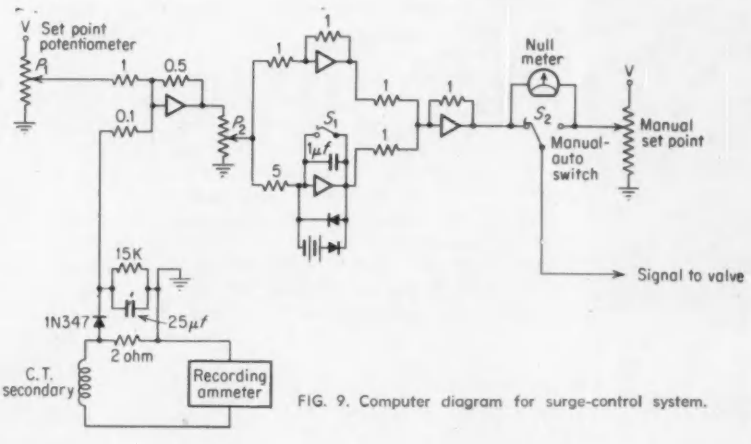
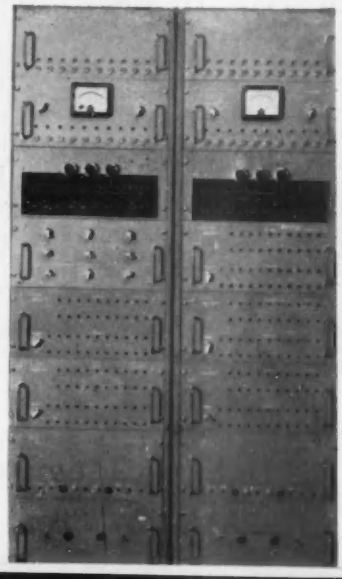


FIG. 9. Computer diagram for surge-control system.

FIG. 10. Analog-computer components arranged for breadboarding control systems.



The Digital Computer as a Process Controller

JOHN W. TIERNEY
CHARLES J. HOMAN
DONALD J. NEMANIC
NEAL R. AMUNDSON
Remington Rand Univac, St. Paul

THE GIST: Continuous processes can be controlled in many ways by digital control systems. This article is an account of a scientific exploration of the problems involved in applying a digital computing controller to a continuous chemical process. It was decided to operate the process at an unstable steady state to provide a control problem that would be somewhat difficult to handle with conventional controllers. Three types of control systems for this process were studied by simulation on the general-purpose Univac Scientific Model 1103 computer. The first is the digital equivalent of the conventional analog feedback control system. The effects of decreasing sampling rates were investigated for this type. In the next system, a second computer provides feed-forward control to reset the conventional controller. The third system incorporates all of the functions of the first two in a single digital computing controller. In this case, a special-purpose digital computer, the Incremental Computer, was set up on the 1103 in dual simulation with the process dynamics.

Success in aircraft applications has proved the practicability of controlling continuous systems with digital computers. Also, the values of using the digital computer as a controller have been well-discussed in previous articles[5, 6]. Rather than put forth the merits of the digital approach in a general way, then, this article describes the results of simulating a specific process application of digital computing control.

A study undertaken to determine the technical problems involved in applying digital techniques to control of a continuous chemical process began with the establishment of certain conditions:

- No attempt was to be made to find the *best* control system. This would have involved the economic values of the product and the plant as well as the control equipment, and also the kinds of disturbances to be expected and the effects of upsets on product quality.
- It was to be assumed that an instrument was available to measure the outlet concentration, A. Actual systems might have to rely on related measurements.
- Lags in sensing elements, transducers and control valves were to be assumed negligible. This could be satisfactory in real systems if the disturbing frequencies are low enough.
- Random disturbances were to be completely excluded (except for round-off errors). Some noise would be present in an actual system.
- The desired value of A was to remain constant throughout most of the study. The control problem was thus one of compensating for disturbances in the inlet temperature or concentration. An actual process would probably be run this way.

The process (see spread, pp. 168 and 169) was simulated by programming Equations P1, P2, and P3 into the Univac Scientific Model 1103 computer at the St. Paul Univac Service Bureau. Nonlinear equations like these are easily handled on a digital computer, and in this case the simultaneous differential equations were solved by a modified Runge-Kutta integration. A basic time interval of $\frac{1}{2}$ sec was used for the integration, which is conservatively short for the long time constants of the process and for the integration technique used.

Note that the process itself was simulated exactly by solution of the original differential equations. The linearization was done only to simplify the determination of the best characteristics for the controller.

The process is unstable, so that any small upset will cause it to move to one of the stable states. Even round-off errors in the digital approximations of the process equations could cause instability, so that special care was taken in programming to make sure these errors would not cause upset. As programmed, the process can run indefinitely at the steady state.

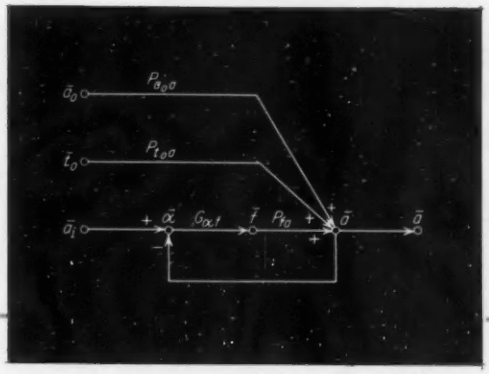
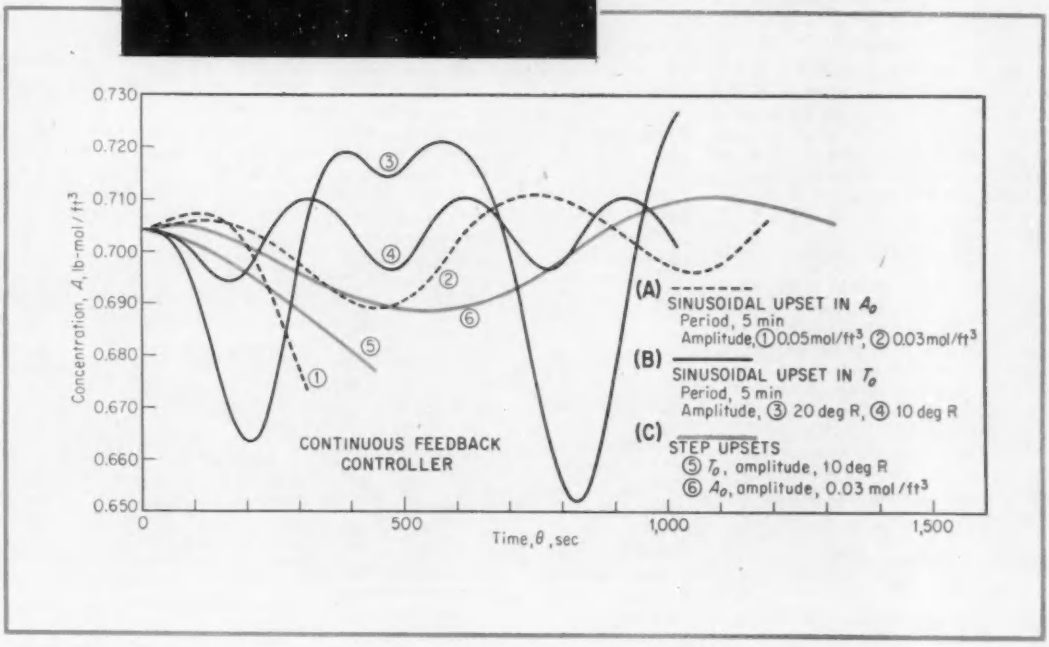


FIG. 1. Signal flow diagram for linearized process with feedback control.

FIG. 2. Response of concentration, A, with continuous feedback controller to: A—sinusoidal disturbances in A_0; B—sinusoidal disturbances in T_0; C—step changes in A_0, T_0.



SIGNAL-FLOW DIAGRAM

The signal-flow diagram is used several times in this article to illustrate the various types of control systems simulated. Note that these control systems are linearized, and that the flow diagrams use Laplace notation. The properties of such diagrams are discussed further in standard texts[2]. The symbol P, together with appropriate subscripts, indicates process transfer functions. G represents controller transfer functions. Although the diagram assumes a linear system, the control system itself could be nonlinear.

Conventional Control System

In Figure 1, a conventional feedback control system has been added to the signal-flow diagram of the process shown in Figure P3. The controller has proportional, derivative, and integral action, and is represented by the transfer function G_{af},

$$G_{af} = \frac{C_1}{p}(p + C_2)(p + C_3) \qquad (1)$$

The linearized equations for Figure 1 are:

$$\bar{a} = \frac{G_{af}P_{fa}}{1+G_{af}P_{fa}}\bar{a}_i + \frac{P_{a_0a}}{1+G_{af}P_{fa}}\bar{a}_0 + \frac{P_{t_0a}}{1+G_{af}P_{fa}}\bar{t}_0 \qquad (2)$$

Any combination of C_1, C_2, and C_3 which make the above equation stable would presumably be satisfactory. Absolute stability is determined by the denominator, the requirement being that when written as a polynominal in p, it will not contain any roots with positive real parts. This can be checked for various values of C_1, C_2, and C_3 by using the Routh test[3]. However, the requirements for absolute stability are insufficient to assure a good control action even for the linear system. The controller should also provide relatively little phase shift for sinusoidal disturbances, as well as high damping, rapid rise, and minimum overshoot in response to transient changes. A set of constants which meet these requirements reasonably well are $C_1 = 52$, $C_2 = 2$, and $C_3 = 1$.

A necessary, although not sufficient, condition for no roots with positive real parts is that all coefficients have the same sign. Thus a minimum derivative coefficient (C_1) is 9.4.

The controller equation can be represented by

$$Q_c - Q_{cs} = 1640\frac{d(A_i - A)}{d\theta} + 24.6(A_i - A) + 0.082\int_0^\theta (A_i - A)d\theta \qquad (3)$$

This equation was solved continuously in the digital computer. The calculation interval ($\Delta\theta$) was $\frac{1}{2}$ sec, (the same as the interval used in the process equations) which is the equivalent of a continuous

AN UNSTABLE PROCESS

The process chosen for study is the apparently simple one that goes on in the reactor of Figure P1. The mixture entering the reactor has a component that will react with itself under proper conditions, and an inert diluting component. Two molecules of the reactive component A react irreversibly as follows:

$$2A \rightarrow \text{Product}$$

The rate of reaction is proportional to the square of the concentration of A in the reactor, the contents of which are assumed perfectly mixed. The letter A is hereafter designated as the concentration of component A, measured in lb-moles/ft³. A simple material balance around the system gives the equation:

$$V\frac{dA}{d\theta} = Q(A_0 - A) - kVA^2 \qquad \text{(P1)}$$

where V is reactor volume in ft³, Q is volume rate of flow in ft³/sec, and θ is time in sec. The equation relates the rate of change of the amount of reactant in the reactor to concentrations in the inflow and outflow and the rate of reaction.

The reaction also evolves heat, some of which is removed by the cooling coil. The accumulation of thermal energy in the reactor can be equated to the difference between heat entering and leaving the reactor:

$$VC_\rho\frac{dT}{d\theta} = QC_\rho(T_0 - T) - \frac{hA_hF}{1+F}(T - T_{co}) - kVA^2(\Delta H) \qquad \text{(P2)}$$

where

$$F = \frac{2Q_{co}\rho_{co}C_{co}}{hA_h}$$

In addition, the reaction velocity coefficient k is a function of temperature:

$$k = k_1 e^{-E/RT} \qquad \text{(P3)}$$

Equations P1, P2, and P3 completely represent the behavior of the process. If the flow rate and other inlet conditions are fixed at the steady state s (numerical values are given in the "Nomenclature", and all the derivatives with respect to time θ are zero) there are three solutions for reactor concentration A, each occurring at a different temperature. Stability analyses of these three steady states show that the high- and low-temperature states are stable, while the intermediate state is unstable. The reactor has no tendency to leave a stable state and assume another state. On the other hand, it will, upon the slightest perturbation, tend to leave the unstable state and pass to one of the stable ones. It has been shown[1] that the unstable state is not actually approached in a transient operation, and also that plots of concentration vs. temperature exhibit all of the types of instabilities possible under proportional control of coolant flow rate using effluent temperature as an indicator of deviation from steady state.

It was decided to attempt to control this reactor at its unstable steady state. While this may be undesirable in practice, it does present a difficult control problem and thus one which is well suited for comparison of control systems.

Linearization

Although Equations P1, P2, and P3 give the correct functional relationship between process variables, they are difficult to interpret. Elimination of temperature between them for example, results in a complicated equation from which it would be difficult if not impossible to obtain an explicit expression for A, reactor concentration. The equation can be simplified by "linearization", i.e., expanding each of the nonlinear variables in a Taylor series, retaining the linear terms. In general,

$$F(x) = F(x_0) + (x - x_0)F'(x_0) + \frac{(x-x_0)^2F''(x_0)}{2} + \cdots\cdots$$

and only the first two terms would be retained. The nonlinear term A^2 for example, could be linearized about A_s:

$$A^2 \cong A_s^2 + (A - A_s)2A_s$$

In the problem under consideration, the state about which linearization is to take place is the unstable steady state. Any value with a subscript s is the value that variable has at the unstable steady state and is a constant.

Thus, Equation P3 was substituted into Equations P1 and P2 and the two resulting equations were linearized as above. Rearrangement of terms produced the nondimensional, linearized forms of Equations P1 and P2 as follows:

$$\frac{da}{d\psi} = -\left(1 + 2\frac{VA_sk_s}{Q_s}\right)(a) - \left(\frac{VA_sk_s}{Q_s}\right)\left(\frac{E}{RT_s}\right)(l) + a_0 \qquad \text{(P4)}$$

$$\frac{dl}{d\psi} = -2\left(\frac{VA_sk_s}{Q_s}\right)\left(\frac{A_s\Delta H}{C_\rho T_s}\right)(a) - \left[1 + \left(\frac{F_s}{1+F_s}\right)\left(\frac{hA_h}{Q_sC_\rho}\right) + \left(\frac{VA_sk_s}{Q_s}\right)\left(\frac{E}{RT_s}\right)\left(\frac{A_s\Delta H}{C_\rho T_s}\right)\right](l) + \frac{T_{co}}{T_s}(l_0) + \left(\frac{F_s}{1+F_s}\right)\left(\frac{hA_h}{Q_sC_\rho}\right)\left(\frac{T_{cos}}{T_s}\right)(l_{co}) - \left(\frac{hA_h}{Q_sC_\rho}\right)\left(\frac{T_s - T_{cos}}{T_s}\right)\left(\frac{1}{1+F_s}\right)^2(f) \qquad \text{(P5)}$$

These equations have the form:

$$\frac{da}{d\psi} = -b_{11}a - b_{12}l + b_{12}a_0 \qquad \text{(P6)}$$

$$\frac{dl}{d\psi} = b_{21}a + b_{22}l + b_{23}l_0 + b_{24}l_{co} + b_{25}f \qquad \text{(P7)}$$

where ψ represents dimensionless time $\theta Q/V$, and the constants are defined by Equations P4 and P5.

Time could be eliminated between these equations rather simply, but it is preferable here to make a transformation of variable. The control engineer's usual tool for the study of linear systems, the Laplace transform,

$$\bar{X} \qquad \int_0^\infty e^{-ps}X(x)dx$$

was thus used to transform the differential equations (P6 and P7) into algebraic equations (P8 and P9), assuming the system to be at the steady state s at time = 0.

$$(p + b_{11})\bar{a} + b_{12}\bar{l} = b_{12}\bar{a}_0 \qquad \text{(P8)}$$

$$-b_{21}\bar{a} + (p - b_{22})\bar{l} = b_{23}\bar{l}_0 + b_{24}\bar{l}_{co} + b_{25}\bar{f} \qquad \text{(P9)}$$

Eliminating $\bar{l}$ between these equations then yields the transform equation for the concentration in the reactor, linearized around state s:

$$\bar{a} = \frac{b_{12}(p - b_{22})\bar{a}_0 - b_{12}b_{23}\bar{l}_0 - b_{12}b_{24}\bar{l}_{co} - b_{12}b_{25}\bar{f}}{p^2 + (b_{11} - b_{22})p - b_{11}b_{22} + b_{12}b_{21}} \qquad \text{(P10)}$$

Substituting numerical values for constants and assuming that $\bar{l}_{co} = 0$

$$\bar{a} = \frac{(p - 2.90)\bar{a}_0}{(p - 2.00)(p + 0.940)} - \frac{12.7\,\bar{l}_0}{(p - 2.00)(p + 0.940)} + \frac{0.113\,\bar{f}}{(p - 2.00)(p + 0.940)} \qquad \text{(P11)}$$

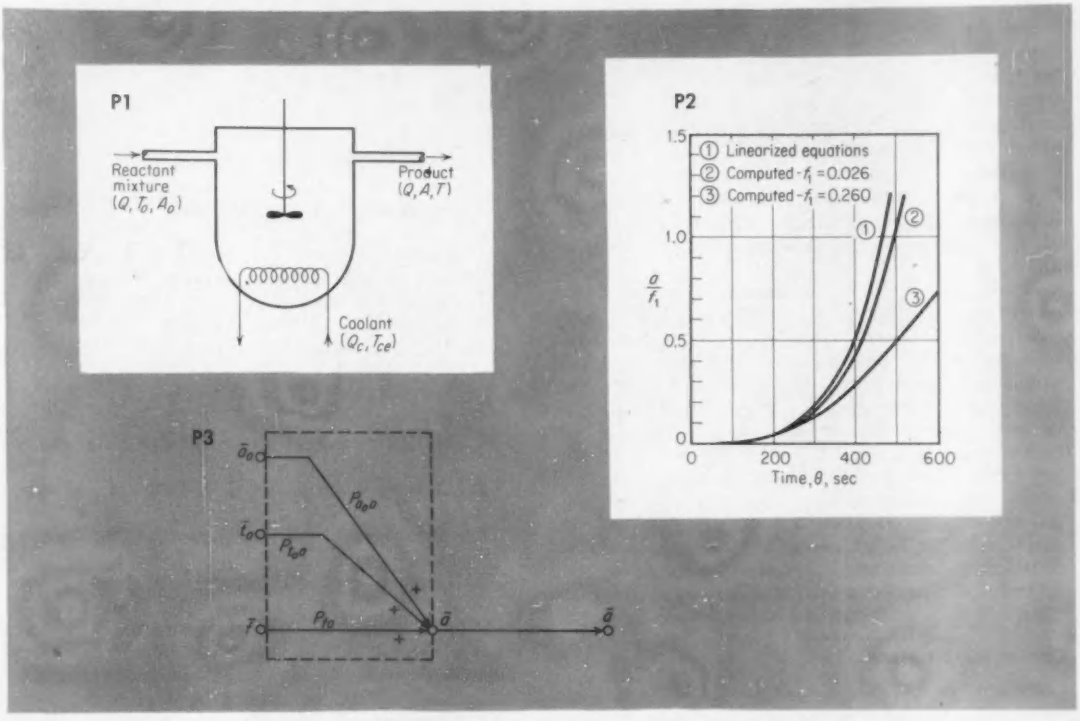
The denominator in Equation P11 has been factored to show the roots. The positive real root in the denominator shows directly that the system is unstable at state s, an advantage of linearization. Linearization also simplifies the problem for small perturbations about the steady state, and permits an estimation of the relative importance of the process variables.

The linearized equations represent the actual process behavior quite well for small disturbances about the steady state. Figure P2 shows the deviation from the actual values of the ratio a/f_1 for sinusoidal disturbances in f_1 with two different amplitudes, $f_1 = 0.026$ or 1 percent of the total flow rate, and $f_1 = 0.260$ or 10 percent of the total flow rate. Linear theory would predict that the ratio is independent of the value of f_1. Actually, however, nonlinearities cause the ratio to vary and the agreement is best for very small values of f_1.

If Equation P11 is written as:

$$\bar{a} = P_{a_0s}\bar{a}_0 + P_{l_0s}\bar{l}_0 + P_{fs}\bar{f} \qquad \text{(P12)}$$

then the linearized process can be represented by the signal flow diagram of Figure P3. The linearized equations indicate that l_0, for example, contributes something to the final concentration, a, and it is convenient to consider this as being the case, but it is not possible in the actual reactor to isolate any concentration measurement as being due to l_0 or a_0. For example, the signals flowing inside the dotted lines of Figure P3 cannot be measured. These signals are in Laplace transform notation, and are added and subtracted at nodes. Between nodes they are operated upon by transfer functions.



NOMENCLATURE

VARIABLES

A = Concentration of A in reactor.
A_i = Desired concentration of A.
A_0 = Concentration of A in inlet.

$a = \frac{A - A_s}{A_s}$

a_c = Calculated set point for continuous controller.

$a_i = \frac{A_i - A_s}{A_s}$

$\alpha = a_i - a$
c = Output of continuous controller.
c^* = Controller output after sampling.

$F = \frac{2Q_cC_{pc}}{hA_h}$, nondimensional flow

$f = F - F_s$
f_0 = Value of f to compensate for input disturbances.
k = Reaction velocity coefficient.
k_1 = Reaction velocity coefficient constant.
Q = Flow rate of reactant mixture.

$q = \frac{Q - Q_s}{Q_s}$

Q_c = Coolant flow rate.

$q_c = \frac{Q_c - Q_{cs}}{Q_{cs}}$

T = Temperature in reactor.
T_c = Average coolant temperature.
T_{ce} = Inlet coolant temperature.
T_0 = Temperature of reaction mixture entering.

$t = \frac{T - T_s}{T_s}$

$t_c = \frac{T_{cs} - T_{ces}}{T_{ces}}$

$t_s = \frac{T_s - T_{ss}}{T_{ss}}$

θ = Time, seconds.
p = Laplace transform variable.

$\psi = \frac{\theta Q}{V}$, Dimensionless time.

ϕ = Sampling interval, ψ units.

TRANSFER FUNCTIONS

G = Controller.
H = Hold circuit.
P = Process.

CONSTANTS

A_h = Area of cooling coil, 500 ft.²
A_s = Concentration in reactor at unstable steady state, 0.704 lb-mol/ft.³
A_{os} = Concentration in inlet at unstable steady state, 1.00 lb-mol/ft.³
C = Heat capacity of reactant mixture, 1.0BTU/lb-deg F.
C_c = Heat capacity of coolant, 1.0BTU/lb-deg F.
$C_1C_2C_3$ = Controller constants.
E = Activation energy, 44,700BTU/lb-mol
F_s = Steady state value of F, 2.60.
f_1 = Amplitude of sinusoidal variation in f.
h = Heat transfer coefficient, 100BTU/hr-ft²-deg F.
H = Heat of reaction,—20,000BTU/lb-mol
k_0 = Reaction velocity constant, 2.7×10^{11} ft³/lb-mol-sec.
k_s = Steady-state reaction velocity coefficient, 2.98×10^{-9}ft³/lb-mol-sec.
Q_{cs} = Steady state coolant flow rate, 0.289ft³/sec.
Q_s = Steady state reactant flow rate, 0.5ft.³/sec.
R = Gas constant, 1.987BTU/lb-mol-deg R.
ρ = Density of reactant mixture, 60.0lb/ft.³
ρ_c = Density of coolant, 62.4lb/ft.³
T_{ces} = Steady state temperature of inlet coolant, 520deg R.
T_{os} = Steady state temperature of inlet reactant mixture, 661.6deg R.
T_s = Steady state temperature of reactor, 700deg R.
V = Volume of reactor, 100 ft.³

or analog controller. To simplify programming, it was assumed that $dA/d\theta$ was available from the process. The integration was done by assuming A constant for each time increment. Since changes in A were normally small, this is a good approximation.

Some results using the continuous controller are shown in Figure 2. A sinusoidal disturbance in A_o for two different amplitudes is shown in Figure 2A, sinusoidal disturbance in T_o in 2B, and step changes in A_o and T_o in 2C. Control of upsets in A_o is more difficult than control of upsets in T_o. This is evident from examination of the transfer functions $P_{a_o a}$ and $P_{t_o a}$. The former has p in the numerator while the latter does not, so that in the former rate of change of A_o enters the control problem as well as the magnitude of A_o.

It can be seen from examination of Figure 2 that an analog controller or its digital equivalent (a very short interval between successive calculations) controls the process well for small disturbances, which would probably constitute the majority of upsets. For larger disturbances, the deviations in concentration become large. In the present case this could be corrected by using a larger value for the derivative control term. This is possible in practice only to a limited extent, however, because of noise and inherent sluggishness or lags in valve actuating equipment. Actually, whether better controller constants could be obtained is unimportant because the controller described above has been used as a base case, and other systems will be evaluated on a comparative basis.

Controller program

One of the most important factors in the application of digital control is the amount of time that the computer spends on the control calculation. This is determined by several things: basic computer speed, number of steps in the program, complexity of the problem, degree of approximation, etc. A look at how the controller was programmed in the 1103 will help to illustrate.

Equation 3 was written as follows for a constant sampling rate $\Delta\theta = \frac{1}{2}$ sec.

$$Q_c - Q_{cs} = 1640\left(\frac{d(A_i - A)}{d\theta}\right)_n + 24.6(A_i^n - A^n) + (0.082\Delta\theta)\sum_{o}^{n}(A_i^k - A^k) \quad (4)$$

The program for this might consist of the following steps:

1. Enter the most recent values of $dA/d\theta$, A, $dA_i/d\theta$, and A_i in appropriate locations.
2. Subtract A from A_i.
3. Subtract $dA/d\theta$ from $dA_i/d\theta$
4. Add result of step 2 to $\sum_{o}^{n-1}(A_i^k - A^k)$
5. Multiply result of step 3 by 1,640 and add to Q_{cs}.
6. Multiply result of step 2 by 24.6 and add to result of step 5.
7. Multiply result of step 4 by 0.041 and add to result of step 6.
8. Transfer new coolant flow rate to computer output.

Steps 2 through 7 take approximately 1 millisec in the Univac 1103. Additional time (the exact amount depends on the analog-to-digital conversion equipment) should be allowed in steps 1 and 8 for record keeping. If this other equipment is as fast as the 1103 an additional 0.5 to 1 millisec is ample. It

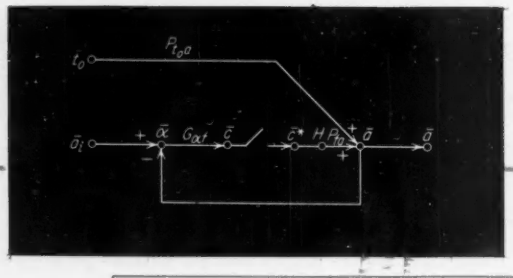


FIG. 3. Signal flow diagram for linearized process using feedback control with sampled output.

FIG. 4. Response of concentration, A, to sinusoidal disturbances in T_o using feedback control with various sampling intervals.

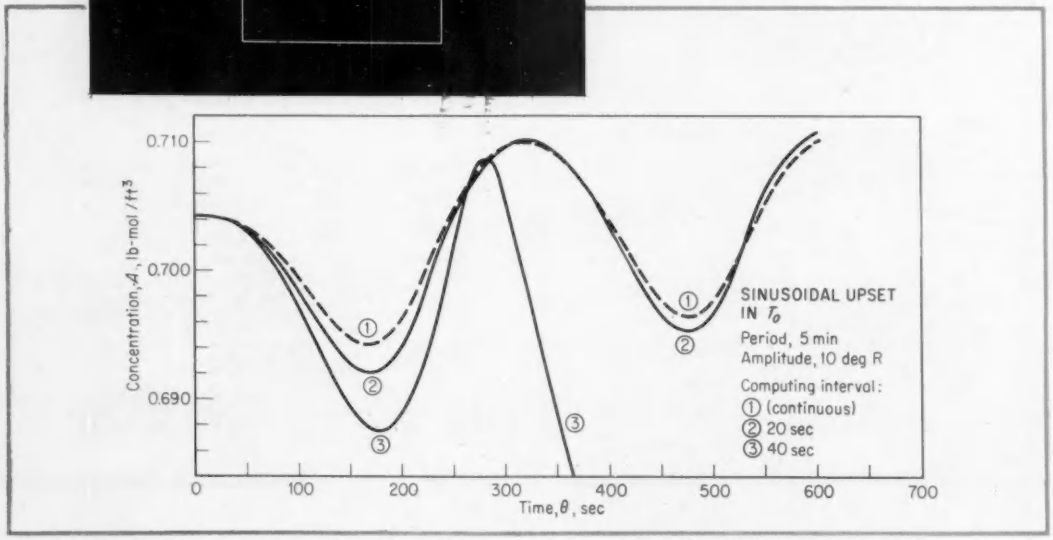
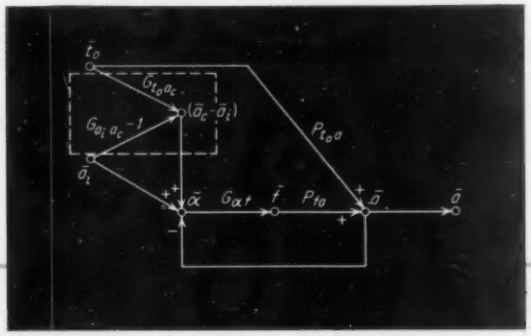
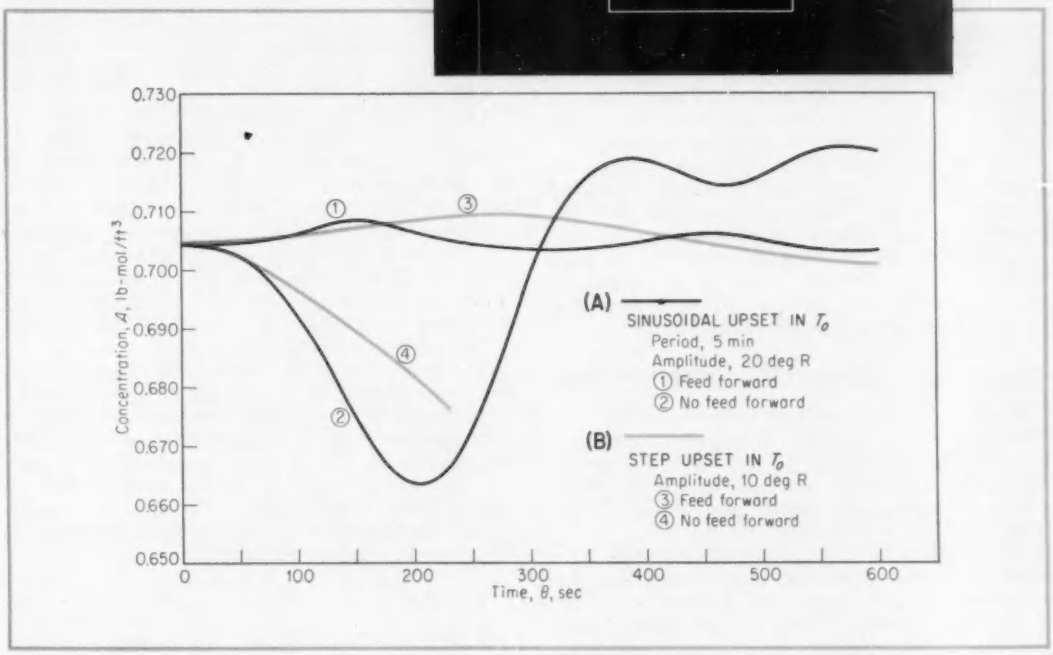


FIG. 5. Signal flow diagram for linearized process using feed forward to modify set-point of feedback controller.

FIG. 6. Response of concentration A, using continuous feedback controller with and without feed forward, to: A—sinusoidal disturbance in T_o, B—step change in T_o.





is not likely, however, that the speed of such a large, general-purpose computer would be available in a practical digital controller.

Sampling Control

A practical digital controller would probably operate at a much slower rate, computing outputs at regular intervals. The longer the period between samples, the less time the computer is used for each control action. If the period is long enough compared to the computing time, the computer may be connected alternately by a commutating switch to each of several other systems, which may then all be controlled by the one computer on a time-shared basis.

In the present example, the output of the controller was programmed so that the time increment between successive calculations could be varied. The control valve was held constant at the last value until a new value was calculated—the equivalent of a simple hold circuit. The signal flow diagram is given in Figure 3. The output of the controller was sampled and put through a holding circuit before controlling the valve. The results of using sampling intervals of 20 and 40 sec are shown in Figure 4.

Using the 20-sec sampling interval, the control action is still almost as good as that of the continuous controller. At 40-sec intervals there is a great difference and control is unsatisfactory, although the system may still be stable. It would therefore be necessary, if using a digital controller, to compute a new control valve position no more often than every 20 sec.

It is important to be able to calculate the effect on stability of a sampling device such as a digital controller in the control system. A sampled-output controller can be analyzed by assuming that the sampling device is equivalent to modulating the signal with a stream of unit impulses. Designating a modulated quantity by an asterisk, the continuous controller output $c(p)$ becomes $c^*(p)$ after sampling. The original signal flow diagram of Figure 3 can then be represented by:

$$a(p) = \frac{G_{af} a_i^*(p) H(p) P_{fa}(p)}{1 + H P_{fa} G_{af}^*(p)} - \frac{t_o P_{t_o a} G^*(p) H(p) P_{fa}(p)}{1 + H P_{fa} G_{af}^*(p)} + t_o(p) P_{t_o a}(p) \qquad (5)$$

A somewhat different functional notation is used here from previous equations because when dealing with sampled functions, $a(p)G^*(p) \neq aG^*(p)$. Analysis proceeds much the same as with continuous functions. The system becomes unstable if any roots of the denominator have positive real parts. The denominator however, is primarily a sampled quantity. It can be expressed as follows:

$$1 + H P_{fa} G_{af}^*(p) = 1 + \left(\frac{5.87(1 - e^{-\phi p})(p+2)(p+1)}{p^2(p-2)(p+0.94)} \right)^* \qquad (6)$$

These sampling process introduces the variable $e^{\phi p}$,

where ϕ is the sampling interval. Letting

$$z = e^{\phi p}$$

the denominator becomes

$$1 + 5.87 - \frac{1.06\phi}{z-1} - 0.997 + \frac{1.02(z-1)}{z-e^{2\phi}} - \frac{0.0245(z-1)}{z-e^{-0.24\phi}} \quad (7)$$

The roots of this cubic equation can be readily determined for a series of values of ϕ. Since the presence of a positive real root in p corresponds to an absolute value of z greater than one, the value of ϕ is increased until one of the roots equals one. This occurs at $\phi = 0.37$ (74 sec) and indicates a root on the imaginary axis in the p-plane, or marginal stability.

Thus the border between a stable and an unstable system in the present example occurs at a sampling interval of 74 sec. When it is considered that the analysis is based on the linearized equations and further, that intervals somewhat less than the marginal value would give control systems which might be stable but would have poor control properties, this agrees well with the actual results in Figure 4.

CONVENTIONAL CONTROL PLUS FEED FORWARD

Whether the conventional control system just described is analog or digital, it responds to disturbances only through upsets in the controlled quantity. Adding "feed forward" by measuring the disturbing variable and using it to adjust the controller should provide better response to larger upsets.

One way to apply feed-forward compensation is to use a continuous (probably analog) controller for the normal feedback control and a digital controller for the feed forward. There are, of course, many other possible arrangements, but this one is of special interest for several reasons:

- The use of a digital feed forward controller in conjunction with conventional analog equipment is a logical extension of present methods.
- The digital controller coordinates several control systems, its flexibility permitting ready adaptation to changing conditions.
- The feed-forward or coordination relations are usually complex, probably nonlinear, calculations which a digital computer is well-equipped to make.

The stabilizing effect of feed-forward control is not as pronounced as feedback control. In the process under study, for example, feed forward can be eliminated, and the process will still be stable, though not as well controlled. If the feedback is eliminated, it is no longer stable. Thus, feed forward should only be used when required—for example, when there is to be a major change in operating level (such as during process start up). The computer might be solving other problems during periods of no change.

The signal flow diagram in Figure 5 shows one possible arrangement for the controllers. The digital controller is represented by the area inside the dotted lines, which includes the transfer functions $G_{t_o a_c}$ and $G_{a_t a_c}$. The continuous controller is represented as before by G_{af}. In this case the output of the digital controller modifies the set-point of the analog controller. It could adjust the controller constants or the valve position f, rather than a_c, but the latter is the more realistic case.

Although the digital controller could be programmed to use the linear control functions ($G_{t_o a_c}$ and $G_{a_t a_c}$), it is almost as easy to use nonlinear Equations P1, P2, and P3. In effect, a mathematical model of the process is constructed in the computer, and variations in T_o and A_t are used to determine desired changes in F. Equations P1, P2, and P3 are programmed in the computer, using as independent variables, A_t and T_o. In the general case A_o, Q, and T_{co} could be included also. The desired concentration, A_t, is used instead of the actual concentration A, and the dependent variable or feed-forward signal is the flow rate of coolant, Q_c, or in dimensionless form, F.

The change in flow rate could be sent directly to the valve, but it is usually easier to modify the controller set-point. Accordingly, the variable a_c is so computed that when put into the controller and operated on by G_{af} it will yield the desired change in flow rate. It might be desirable to feed a_t directly to the continuous controller if the digital system is not being used; in this case, the calculated set point a_c is modified by subtracting a_t.

The process itself has already been programmed in the computer, and an exact model of it could also be programmed for the controller. But such an elaborate technique as simulation is not needed and would not be justified—a much cruder approximation is good enough. For example, it can be assumed that all inputs except t_o are constant. Equations P1 and P3 remain unchanged, and only the following terms in Equation P2 need be considered

$$0 = QC\rho(T_o - T) - \frac{FhA_h}{1+F}(T - T_{co}) - kVA(\Delta H) \quad (8)$$

Substituting for constants, the resultant equation for f is

$$f = F - F_s = \frac{30T_o - 18045}{20540 - 30T_o} - 2.60 \quad (9)$$

A quantity a_c must now be computed that will yield the desired value of f when operated on by G_{af}. The final expression for the present value of a_c is

$$a_c^n = \frac{\Delta\theta\left(f^n - 0.52\sum_{o}^{n-1} a_c^k\right)}{15{,}600} + 1.33a_c^{n-1} - 0.332a_c^{n-2} \quad (10)$$

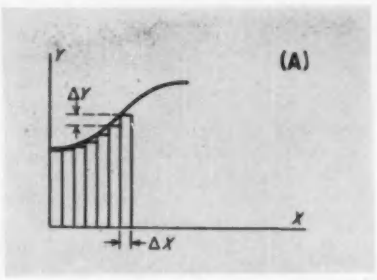
Figure 6 shows the results of a run using a continuous controller only and one using a continuous controller plus feed forward. The feed forward has resulted in a significant improvement in control.

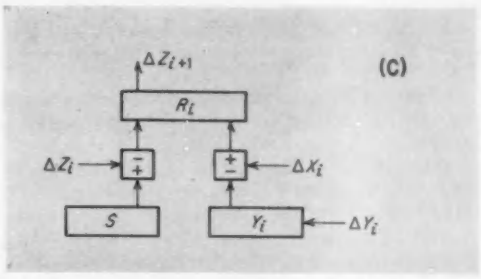
COMPLETE DIGITAL CONTROLLER

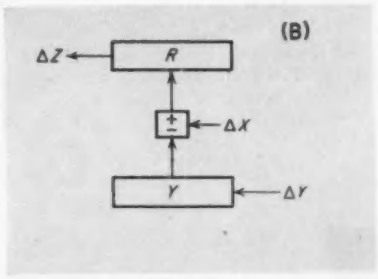
The last possibility to be considered is the use of a digital computer for the complete control action, both feedback and feed forward. A general-purpose computer does not operate at peak efficiency in solving any particular problem. Though it is fast enough to deliver the valve outputs at the required rate, continuous solution of the same set of differential equations is probably uneconomic. One alternative is the special purpose digital computer which sacrifices computing versatility for more efficient computing.

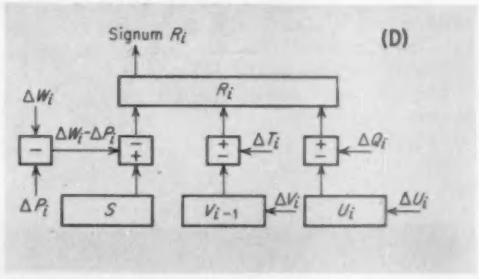
The "Incremental Computer" (see box), a special-purpose machine developed for an airborne-control application, was simulated by a special program

THE INCREMENTAL COMPUTER









The Incremental Computer, a small, lightweight machine designed for a special control application[4], is an extension of digital differential analyzer techniques. The basic operation in a digital differential analyzer is an integration carried on by a summation process:

$$\int y dx \approx \Sigma Y \Delta X$$

(Figure A). The basic integrator normally consists of two registers, R and Y (Figure B). The contents of the Y register, the initial value Y_o plus the summation of the ΔY input pulses, are added to or subtracted from the R register under the control of the ΔX pulse. The output of the R register is its overflow ΔZ. Thus with proper scaling

$$\Delta Z = Y \Delta X \text{ and } \Sigma \Delta Z = \Sigma Y \Delta X \approx \int y dx.$$

A scale factor may be added to this basic unit, as shown in Figure C. In this case, the scale factor, S, is subtracted from or added to the contents of the R register in accordance with the value of the ΔZ pulse. ΔZ is referred to as the signum of the R register

$$\text{i.e., } \Delta Z = +1 \text{ if } R \geq 0, \text{ and } \Delta Z = -1 \text{ if } R < 0.$$

Then

$$\Sigma \Delta Z = (1/S) \Sigma Y \Delta X \approx (1/S) \int y dx.$$

Here it may be noted that ΔZ represents the number of integral times that S may be subtracted from the summation of $Y\Delta X$ and the remainder remains in the R register.

The Incremental Computer solves a single basic equation for each step of a program. This basic equation is an algorithm that may be rearranged to perform many different mathematical operations. The equation used (Figure D) is:

$$R_i = R_{i-1} + U_i \Delta Q_i + V_{i-1} \Delta T_i - S(\Delta W_i - \Delta P_i)$$

The R, U, V, and S values are stored on a drum. The incremental values ΔQ, ΔT, ΔW, ΔP, and the increments ΔU, and ΔV, are stored in a 64-bit core memory. These increments may only have one of two values, either plus one or minus one, unless the particular step is programmed to omit that increment from the general equation (e.g., if ΔP is not programmed for a particular step, the equation for that step is

$$R_i = R_{i-1} + U_i \Delta Q_i + V_{i-1} \Delta T_i - S \Delta W_i).$$

The Δ quantities represent the inputs to a step and the signum of R_i represents the output of the step.

Nine mathematical operations may be performed by special algorithms arising from the basic algorithm. These nine are: addition or subtraction, multiplication, division, square root, integration, differentiation, integration with reciprocal integrand, logarithms, and exponentials. Any of these requires only one step in a program. Other computations, such as sine and cosine, are also possible but require two or more steps.

As an example, the algorithm is used to multiply as follows: If $Z = XY$, represent this by $C\,Z = XY$, where C is a scale factor. In the Incremental Computer, let $S = C$, $U_o = X_o$, $V_o = Y_o$. Program $\Delta U_i = \Delta T_i = \Delta X_i$, $V_i = \Delta Q_i = \Delta Y_i$, and $\Delta W_{i+1} = Z_{i+1}$ = signum $R_i S$. ΔP is not programmed and therefore equals zero. The basic algorithm then reduces to the special multiplication algorithm.

$$R_i = R_{i-1} + X_i \Delta Y_i + Y_{i-1} \Delta X_i - C\Delta Z_i \text{ or } \Delta R_i + C\Delta Z_i = X_i \Delta Y_i + Y_{i-1} \Delta X_i$$

By summing over many cycles and noting that $\Sigma \Delta R_i$ is driven toward zero,

$$C\Sigma\Delta Z_i = \Sigma X_i \Delta Y_i + \Sigma Y_{i-1} \Delta X_i = \Sigma X_{i-1} \Delta Y_i + \Sigma Y_{i-1} \Delta X_i + \Sigma \Delta X_i \Delta Y_i = \Sigma \Delta (X_i Y_i)$$

on the 1103 computer to test a completely digital controller. By phrasing the control problem in the logic of the Incremental Computer, the results of using such a computer to control the process were studied. The operating program was thus a dual simulation involving the Incremental Computer and the process, and both simulations were solved simultaneously in the 1103.

The signal flow diagram used is shown in Figure 7. Since all cumputing is now done in the Incremental Computer, the feed forward can be added at the coolant flow rate, f, rather than at the controller set-point. Except for this modification, the diagram is the same as in Figure 5.

Since the digital controller is once again able to solve the nonlinear equations with relatively little additional effort, these equations, rather than the transfer functions $G_{a_o f_c}$ and $G_{t_o f_c}$, were programmed. It would be possible to use a nonlinear expression for the feedback function G_{af} if that were desirable. G_{af} cannot be eliminated because it is necessary for stability; even roundoff errors in the equations themselves will cause the process to become unstable unless G_{af} is included. For easy comparison, values for G_{af} are made the same as before.

The equations were programmed for the incremental computer as

$$T = -4.45\times10^{-5}\, ln\, \frac{Q(A_o - A_i)}{2.70\times10^{15}A_i^2} \qquad (11)$$

$$F_c+1 = \frac{13.9\,(T-T_{ce})}{6{,}000\,\frac{dT}{d\theta} - 30.0(T_o-T) - 5.4\times10^{17}e^{-22{,}500/T}A_i^2 + D}$$

Where $D = 13.9\,(T-T_{ce})$ (12)

$$F = F_c + 14{,}760\,\frac{d(A_i-A)}{d\theta} + 221(A_i-A) + 0.74\int_o^\theta (A_i-A)\,d\theta \qquad (13)$$

and were solved in the order indicated. The total number of program steps required was 24, of which seven were required for Equation 11, eight for Equation 12, four for Equation 13, and five for inputs not included in the program. The resultant control action is quite versatile, providing that the variables A_o, T_o, A_i, Q, and T_{ce} be used for feed forward and that A be used for feedback. At the programmed speed of 10 computations per second, the computer could handle 1,000 program steps. Note that the program used accounted for all nonlinearities in Equations 11 and 12 (some simplification would be justified in any actual problem), and that all quantities calculated are available for any other control action in the computer. Thus control of two or more closely related operations requires fewer program steps.

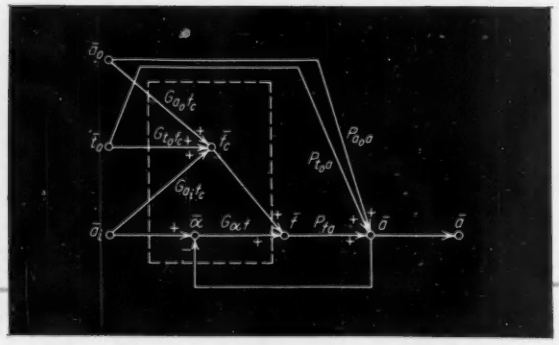
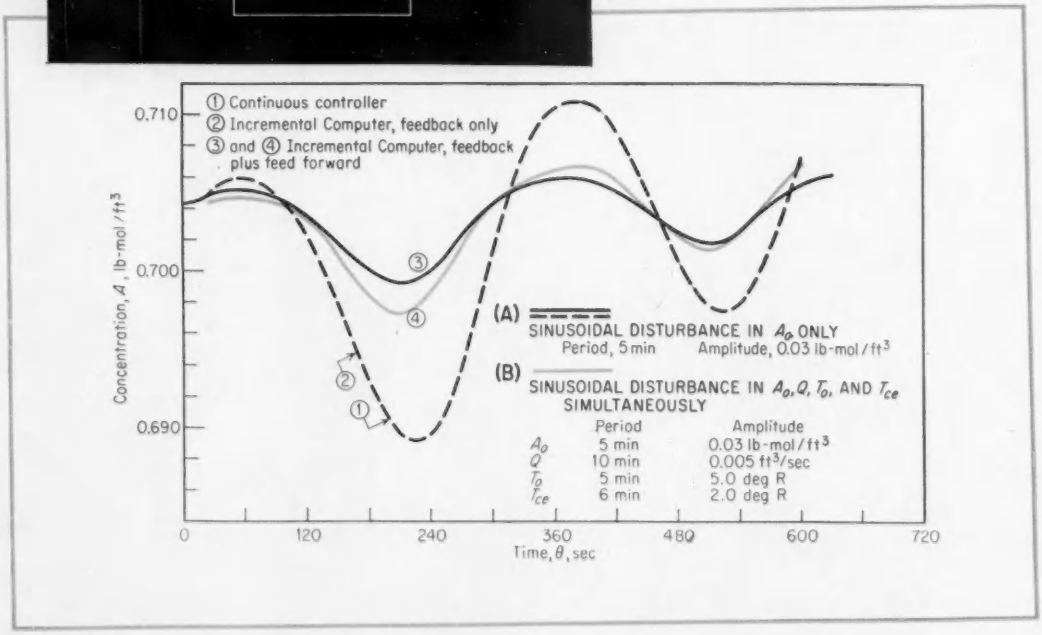


FIG. 7. Signal flow diagram for linearized process using single controller for feedback and feed forward.

FIG. 8. Response of concentration, A, to: A —sinusoidal disturbances in A_o using continuous feedback controller, incremental computer with feedback only, and incremental computer with feedback and feed forward; B—simultaneous sinusoidal disturbances in A_o, Q, T_o, and T_{ce} using incremental computer with feedback and feed forward.



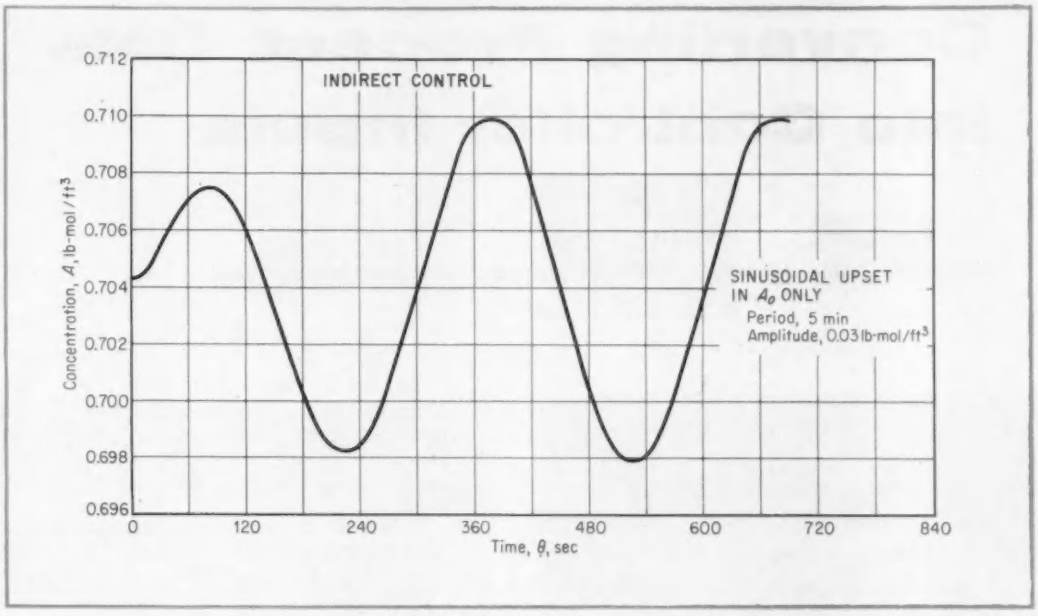


FIG. 9. Response of concentration, A, to sinusoidal disturbances in A_0 using incremental computer with proportional control of temperature and feed forward of temperature set-point.

Figure 8 gives the results of using the incremental computer to control the process with an upset in A_0. Incremental computer control using only proportional, derivative, and reset action is essentially identical to that of the continuous controller. Again the addition of feed forward makes a significant contribution to process stability. The disturbance in A_0 is large—amounting to approximately a 10-percent change in amount of reaction taking place.

To simplify interpretation, only one disturbance at a time was used in the discussion. The real advantage of computer control, however, is its ability to handle a number of disturbances. To illustrate this, the process was given the following disturbances:

Variable	Amplitude	Period
A_0	0.03 lb moles/ft³	5 min
T_0	5.0 deg R	5 min
Q	0.005 ft³/sec	10 min
T_{c0}	2.0 deg R	6 min

All disturbances are sinusoidal primarily because of convenience in programming. Amplitudes and periods were selected arbitrarily. The behavior of concentration using the Incremental Computer is shown in Figure 8B, and it can be seen that control is very good. For this run, the computer speed was increased to 40 cps, a more realistic speed in that scaling and programming problems are simplified.

Indirect Control

Up to now it has been assumed that a measurement of product concentration was available. In many cases this would not be possible, and it might be necessary to control some other quantity, such as temperature. There will then be a necessary offset when changes in operating conditions occur, although this offset can be reduced by using feed forward to adjust T_i, the desired temperature. Proportional feedback control is sufficient to control temperature, while derivative action is necessary for concentration control. If a digital computer is used, the control action can be nonlinear. The response of the process to an upset in A_0 using proportional control of temperature with feed forward on temperature set-point is given in Figure 9. Since this control action is shown simply to illustrate the above principle no attempt was made to optimize the proportional constant used.

Many other modifications of controller action can be made. For example, it might be desirable to sense temperature and use it on the righthand side of Equation 12 even though concentration is sensed also.

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Converting Process Data into Controller Inputs

ROBERT O. MAZE, Aeronautical Div., Minneapolis-Honeywell Regulator Co.

THE GIST: After establishing the equations to be solved by the computing-controller and instrumenting these equations by means of analog or digital equipment, there are still two very important functions to be taken care of—getting information about the process into the computing-controller, and converting the information output of the controller into a form in which it can do useful work in manipulating the process variables. This article tells how to join the process to the computing-controller; the next article starts at the controller output and works back to the process.

Author Maze deals with the basic problem of measuring process variables. The techniques are those that apply to the measurement of variables in any control system, except that more attention is paid to digital representation and to the more accurate measurement necessary for a computing-control system. No attempt is made here to survey transducers; instead the emphasis is on how to obtain a signal from a typical transducer that truly represents the physical quantity at the proper instant, and on how to convert this signal into a form that is acceptable to a computing-controller.

To transfer information from the process to the computing-controller, transducers and possibly signal conditioning units are required, Figure 1. To specify the equipment in this link, four questions must be answered:

1. What type of transducer is necessary to obtain the desired process information? If a suitable transducer is not available, what alternatives can be considered that are compatible with computer input requirements?
2. How does transducer loading affect the process?
3. What signal conditioning equipment is necessary to match transducer output to controller input?
4. Is the transducer located so far from the computing-controller that special data transmission techniques are necessary?

All of these points are considered in the following material. Particular attention is paid to the digital techniques, since they are in general less well known than the analog.

Transducer selection

Picking the right transducer involves balancing transducer characteristics against desired system performance and the input requirements of the controller. Characteristics of innumerable transducers are available elsewhere. A comprehensive listing of the more basic analog transducers has been compiled by M. T. Nadir[7] and several books on the subject of industrial instrumentation have large sections devoted to transducers[2, 8]. Newer devices are covered in technical articles[4, 5]. Most of the published literature has dealt with analog transducers—the digital devices have only recently become important and the techniques are changing rapidly. Besides, many of the so-called digital transducers are so similar to analog devices that establishing separate basic lists would be redundant.

A physicist thinks of transducers as devices capable of converting energy from one system to another, but the control engineer broadens this definition to include devices that are capable of converting information from one system to another. Under the latter definition, devices such as the piezoelectric pickoff and the thermocouple, which actually convert energy from one form to another, are grouped alongside strain gages, synchros, and potentiometers which are not energy converters at all but merely modulators of energy

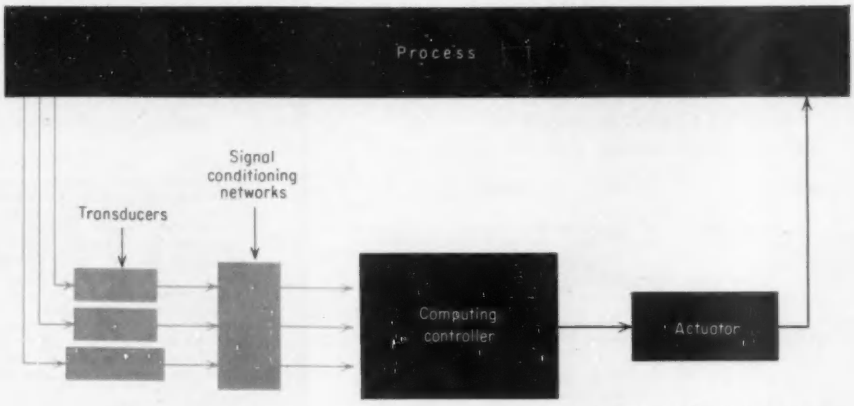


FIG. 1. Joining the process to the computing-controller.

supplied by excitation sources. Note that certain devices, such as ac induction generators, function as energy converters even though they are excited from an external source. Energy converters are sometimes referred to as "self-generating", particularly if they require no external excitation.

The known physical interrelationships offer almost an endless source of transducers. Table I lists many of the basic physical principles with some examples of transducers that make use of each principle. Most of these devices are analog, but as will be pointed out later, the same principles can be used in digital devices or in devices with built-in analog-to-digital converters.

Transducer specifications

The list of specifications in Table II helps in the selection of a transducer for a particular application. Of course, in a given situation all of these may not be pertinent, but it is impossible to make any general statement as to the most important, since this is a function of the system in which the device is applied.

The importance of the compatibility of transducer specifications and system requirements can be illustrated by the selection of a flowmeter for controlling the flow of liquids to be combined in a continuous flow operation. Assume that the ratio of maximum to minimum combined flow is 10:1 and that the mixture can vary over a ratio of 5:1. The mixture must be controlled to within plus or minus 5 percent of the desired ratio under the most adverse condition. If there is an equal division of error, this combination of specifications means that the flow transducer must be accurate (terminal linearity, see Table II) within one part in 2,000. If suitable flow transducers with this dynamic range are not available, it may be advisable to parallel two or more units with overlapping ranges, choosing the proper unit for each flow condition.

In this application, the sensitivity specification is not important unless the transducer must operate near zero flow. On the other hand, transducer resolution must be consistent with the linearity specification, i. e., must be much better than one part in 2,000 (say 1 part in 10,000). The resolution specification depends somewhat, however, on the capabilities of the computing-controller and the output control devices. If either of these has a high threshold, it may not be worthwhile to attempt to hold an inordinately critical resolution at the transducer. Temperature variations of the fluid usually seriously affect flow transducers. In many cases it is most convenient to accept temperature errors in the transducer, provided they are repeatable, and compensate for them in the flow measuring subsystem or in the controller.

The load that the transducer exerts on the process is covered in the specification of input conditions. For example, orifice plates, widely used as flowmeters, may have to yield to the electromagnetic induction or sonic flowmeter in cases where viscous fluids or very-high-velocity flows generate high pressure drop and/or noise. Fluid density variation is another input condition specification. If extreme density variations are encountered, it may be advisable to use a true mass flowmeter[4].

If the signal output of the flowmeter is not compatible with the input requirements of the computing controller, auxiliary equipment will be required to modify transducer output. Almost all complex metering devices require output amplification, and this is accomplished either in the metering subsystem or in an auxiliary amplifier. If the controller is digital, analog-to-digital encoding devices will probably also be required.

Coupling the transducer to the process

Transducer dynamic response and transducer loading on the process are closely related. To show this relationship, couple a temperature sensor, such as a thermocouple, temperature-sensitive resistor, or thermistor, to a process. Figure 2 shows a simplified electrical analog of the sensor in which R_P represents the conductive coupling to the process, R_T the conductive heat loss from the sensor, and C_H the heat capacity of the sensor. The sensor temperature T_2 and the process temperature T_1 are related by

$$\frac{T_2}{T_1}(s) = \frac{1}{1+(R_P/R_T)+R_P C_H s}$$

It is apparent from this equation that there are three ways of improving the dynamic response of the temperature sensor to changes in process temperature:

1. By improving the coupling to the process, which is equivalent to reducing R_P. This can be done by locating the sensor at a point where the flow velocities are greater, or by using a blower or agitator.

TABLE I

HOW BASIC PHYSICAL PRINCIPLES ARE APPLIED TO SIGNAL TRANSDUCERS

PRINCIPLE	TRANSDUCER
MAGNETIC	
Permeability, paramagnetism	Gas analyzers, composition analyzers
Variable transformer	Synchro, inductosyn, goniometer
Variable reluctance	Microsyn, differential transformer
Saturation	Magnesyn, flux-gate magnetometer
CAPACITIVE	
Area, spacing	Capacitive pickoff, micrometer
Dielectric constant	Liquid-level gage, composition meter
RESISTIVE	
Pressure sensitivity	Strain gage, pressure sensitive plastics (force, acceleration, pressure)
Thermal effects	Thermistor, resistance thermometer, hot-wire anemometer
Humidity effects	Relative humidity sensors
SWITCHING, COMMUTATION	Mechanical analog-to-digital converters, choppers, potentiometers
AMPERE'S LAW	Galvanometer, wattmeter
COULOMB'S LAW	Electrometer
ELECTROMAGNETIC INDUCTION	Microphones, flowmeters, ac and dc tachometers, fluxmeters
THERMOELECTRIC	Thermocouple, thermopile, thermocouple pyrometer
ELECTROCHEMICAL POTENTIAL	pH meter
PARTICLE AND RADIATION	Thickness gage, density meter, infrared gas analyzer
ABSORPTION	
Photoemissive, photoconductive	Photocell, digital pickoffs
Ionization, fluorescence	Scintillation counter, G-M tube, ionization chamber, alpha gage
REFRACTIVE INDEX	Liquid-presence indicator
THERMAL CONDUCTIVITY	Pirani gage, gas analyzer
SONIC	
Doppler effect	Sonic flowmeter
Echo ranging	Liquid level gage, sonar
Transmission losses	Density compensation
MOMENTUM	
Newton's Second Law	Accelerometers, true-mass flowmeters
DYNAMIC PRESSURE	Orifice, venturi flowmeters, pitot tube
BUOYANCY	Density meter, level switch
VOLUMETRIC DISPLACEMENT	Free rotor, bellows, vane flowmeters
STATIC PRESSURE	Liquid weight gages — pressure cell, bubbler
THERMAL EXPANSION	Gas thermometer
PHASE CHANGE	Phase-change temperature cell
PIEZOELECTRIC	Accelerometers, force transducers microphones
MAGNETOSTRICTIVE	Microphones, force pickoffs
NUCLEAR AND ELECTRON RESONANCE	Magnetic flux meter
VIBRATING WIRE, REED	Accelerometer, pressure gage
GAS PLASMA, ELECTRICAL EFFECTS	Decker delta transducer
HALL EFFECT	Magnetic flux meter
STREAMING POTENTIAL	Fluid pressure transducer

TABLE II

CHECK LIST OF TRANSDUCER SPECIFICATIONS

ACCURACY

Linearity is the measure of proportionality constancy between input and desired output function. It may be specified as terminal linearity or independent linearity. Terminal linearity is the deviation from the desired function when the function is scaled to include zero and maximum output points. Independent linearity is deviation from the best-fit straight line. Accuracy of trigonometric devices such as resolvers and synchros is often specified in terms of equivalent angular error.

Resolution is always limited by background noise level, but in devices such as potentiometers, digital shaft-position pickoffs, etc., there is a finite limit to resolution determined by the construction of the device. Dead zone is another term used in this connection, and backlash may have a similar limiting effect on resolution.

Stability or repeatability is the ability to maintain constancy of calibration over a long perod of time despite temperature variations or the presence of vibration, shock, or rough handling.

SENSITIVITY

Sensitivity is usually expressed as the ratio of output to input. Sometimes referred to as responsivity.

Threshold is the minimum input level which will cause a corresponding perceptible change in output.

Equivalent noise is defined as the input signal that will produce an output power equal to the noise.

INPUT-OUTPUT CONDITIONS

The kind of input, i.e., mechanical, electrical, radiation, etc., and the kind of output must obviously be compatible with the rest of the system. The range of usable inputs and outputs must also be satisfactory.

The output impedance must be compatible with the load.

Input loading on the measured process is important in determining suitability of transducers for low power-level processes.

DYNAMICS

For essentially linear devices the transfer function can be expressed by a differential equation. For nonlinear devices, experimental curves may be required or approximations may suffice. Digital devices with triggered readout have dead times; some analog devices have fixed delays of sufficient magnitude to limit their use. Dynamic effects may be associated with backlash and dead zone in an otherwise linear device.

PHYSICAL CHARACTERISTICS

Size, weight, shape, mounting dimensions, etc.

INITIAL COST AND AVAILABILITY

Be sure to consider complete installation costs when computing initial costs. This may be particularly high when retrofitting to existing equipment.

RELIABILITY AND MAINTAINABILITY

The ability of the device to perform consistently not only in the laboratory, but also after being serviced by field personnel.

TOLERANCE OF ENVIRONMENT

Can the device maintain required accuracy despite extremes of temperature and pressure; corrosive, humid, or dusty atmospheres; vibration, shock or steady acceleration; and radiation such as gamma rays or neutrons.

POWER REQUIREMENTS

2. By reducing the load that the transducer imposes on the process. For example, by decreasing the heat capacity of the sensor, C_H, through the use of a less massive construction.
3. By adding a compensating network between the temperature sensor and the computing-controller. The lead network of Figure 3, which has a transfer function

$$\frac{V_O}{V_I}(s) = \frac{1+R_1Cs}{1+(R_1/R_2)+R_1Cs}$$

can be used for this purpose where V_I is the signal input from the transducer and V_o is the signal output to the controller.

Note that the load the tranducer exerts on the process can also be reduced by dynamic means as well as by redesigning the sensor. An example is the use of force balance in force, pressure, and acceleration transducers. In both force transducers shown in Figure 4, a differential transformer is the basic motion sensor. In Figure 4A the force being measured is resisted by the spring, which in turn loads the process, while the output is calibrated to read force per unit spring displacement. But in Figure 4B the output of the differential transformer is amplified and applied to a rebalance motor, producing a force that opposes the applied force. With high amplifier gain the differential transformer core moves very little and the input loading is low. A tenfold increase in the natural

frequency is typical of the response improvement that can be obtained with this technique.

Encoding and data transmission

It is not always possible to place the computing-controller close to the process. Economics or physical inaccessibility may make it necessary to run long lines from the transducer to the controller or to use radio comunication links. Reasonably long lines can be used with analog transducers, providing the delay due to propagation along the link is not an appreciable factor in system response, and provided the attenuation caused by the cable or tubing is known or negligible. However, if high precision is required, and particularly if the cable attenuation is variable in an uncontrolled fashion, as in a radio link or over commercial telephone lines, special techniques such as frequency modulation or pulse-code modulation must be used.

The subject of optimum encoding has received considerable attention from the information theory approach[6]. A few simple examples will help to show the techniques that can be used. Disturbances encountered in transmission systems are of four general types:

1. Pickup of the power frequency or other discrete frequencies.
2. Pulsed random noise, such as atmospheric noise (sferics) or cross-talk from pulses in other channels.
3. Random variations in transmission attenuation, such as fading in radio communication or switching and amplifier gain variations in wire transmissions.
4. Variable signal delay due to ionospheric variations or changing cable lengths. This can be dismissed as trivial unless interplanetary distances are involved.

The first and second types of disturbances can be reduced by choosing a band of transmission frequencies that minimizes the interference source. If interference occurs at discrete known frequencies, effective reduction can be obtained by using a carrier frequency known to be clear. If there is no prior knowledge of clear frequencies, pulsed signals can be used. Conversely, if the interference is of a pulse nature, data transmission by narrow-band signals such as frequency modulation will minimize pickup. Attenuation variations can be counteracted by encoding the information in terms of time rather than amplitude, as in pulse-time or frequency modulation. Where signals are transmitted over more than one communications channel, interference can often be minimized by correlation detectors or the less sophisticated but similar coherent phase detectors.

Digital transducers

Digital data is defined as the information present in a signal in terms of the presence or absence of specified levels, including the presence or absence of a given polarity or of discrete separable levels of output. Serial digital data consists of a pulse train on a single channel, with the information represented by discrete levels occurring in a given sequence. Serial digital transmission might be considered normal, since parallel transmission wastes communication channels except when interconnecting components within or physically close to the computing-controller. In parallel digital transmission the exact time that the pulses occur may not be important, since the information is represented by the presence or absence of various combinations of discrete signals on a number of parallel channels. To transmit binary digital data, only two discrete levels are used, the ON signal at some arbitrary positive level and the OFF signal at zero level or in some cases at an arbitrary negative level.

A digital transducer is a measuring device that produces a digital output signal representing the measured quantity. Not all of these devices produce a digital output compatible with the associated digital computing-controller. In some cases the digital output consists merely of pulses, with the number of pulses corresponding to the measured quantity. Here, and in other cases where the transducer does not directly produce a compatible code, code conversion

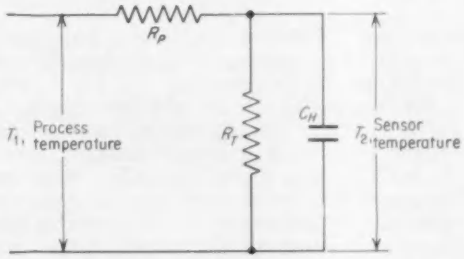


FIG. 2. Electrical analog of temperature sensor coupled to process.

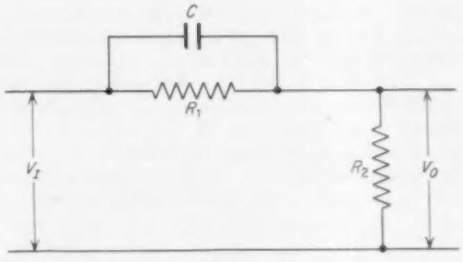
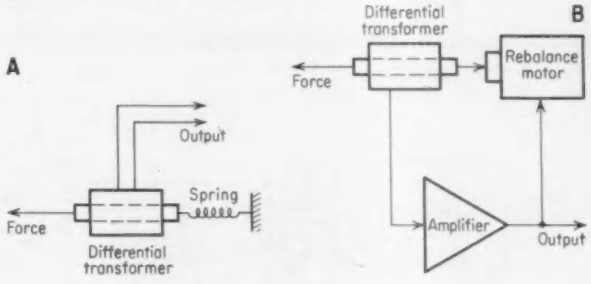


FIG. 3. Lead network for improving transducer response.

FIG. 4. Force transducer without force balance, A, and with force balance, B



is necessary. This is accomplished in a separate code converter and sometimes in the computer itself through suitable programming.

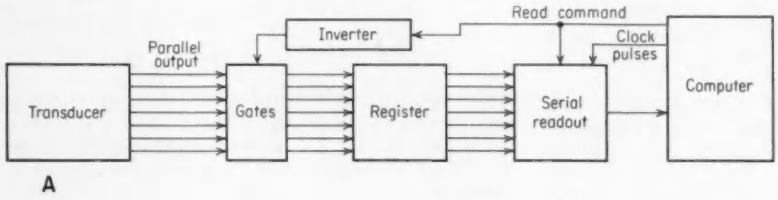
The characteristics of the quantity being measured (is this quantity basically digital, i.e., countable in discrete units, or is it actually analog?) determine the feasibility of a digital transducer. Most quantities are analog in the sense that they vary in an essentially continuous manner. Examples of basically digital information are the number of units passing a given point in an assembly line, the number of identical pellets of an additive introduced into a mixture, and the number of strokes of a pump or a press. Analog quantities include temperature, fluid flow, mass, etc.

Physical quantities are all fundamentally digital in the sense that they vary in discrete quanta or steps. The quantity of liquid in a container is best described by the number of each type molecule (or ion) that is present. Radiant energy measurement involves the detection of discrete photons, alpha particles, or other types of particles. On this basis it might be argued that the ultimate in transducers are digital devices based on the principles of quantum physics; e.g., by counting molecular collisions.

Unfortunately, this ultimate digital nature of the universe is normally of little value to the control engineer. The processes that interest him are going on at a scale where macroscopic measurements are necessary. The cost of equipment sensitive enough to measure down to the nearest quantum is not warranted. Even in situations where separate events can be measured, the randomness of natural processes causes difficulties.

Therefore, the conclusion is that almost all transducers are basically analog devices. Digital transducers are generally analog devices that have the ability to convert to digital output. The only exceptions are found where quantities are measurable to the required degree of resolution to obtain readings interpretable in terms of individual quanta. The required resolution varies considerably, since the individual quanta might be railroad cars on one hand or fundamental particles such as electrons or photons on the other.

Several mechanical input transducers with integral digital conversion are available for measuring angular displacement (shaft position)[8, 9, 10] and linear motion[12, 13]. A number of devices have been constructed for measuring such things as pressure, tempera-



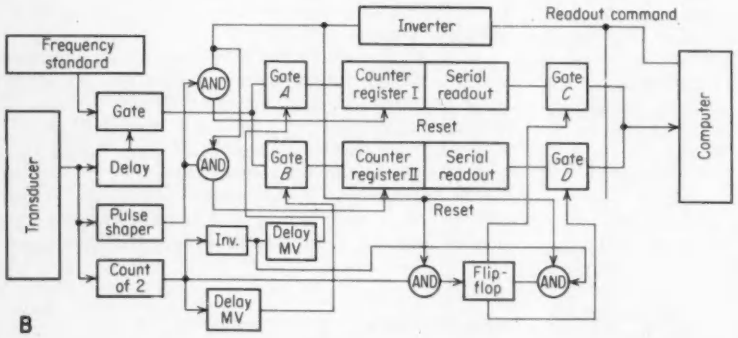
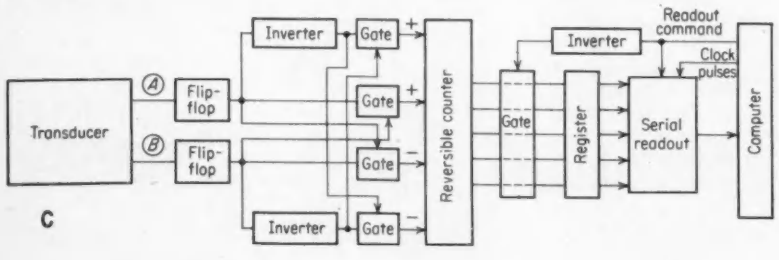


FIG. 5.
Adapting transducer output to digital controller input
A. For a digital transducer with a parallel coded output
B. For a transducer with a pulse-time-modulated output
C. For a transducer with an incremental output



ture, fluid flow, and other quantities in digital terms. Digital output devices other than shaft position and linear motion encoders tend to be as complex as comparable units using an analog transducer and an analog-to-digital converter. For this reason, if an analog quantity other than mechanical motion is to be transduced and fed into a digital computer, it is generally advisable to use analog transducers, a sampling switch, and a single voltage-to-digital converter[9, 14]. Of course there are exceptions to this rule: data transmission problems may require digital encoding, the rapidity of switching may make mechanical switches unsuitable, and sometimes a unique digital solution is available that just fits the application.

There does not appear to be a rapid trend toward the development of digital devices based on the inherent digital nature of physical processes. Instead, packages that combine an analog transducer and a converter will probably be used where the remote location of a transducer makes it desirable to transmit digitally encoded data to the computer-controller[7].

Time coding of analog data

By definition, analog pulse-time and frequency-modulated signals are not classified as digital since they are not quantized. However these coding techniques yield many of the advantages of strictly digital codes, particularly freedom from transmission attenuation effects, ease of switching, and ease of storage. Signals of this type are produced by radar and sonar, by some flow and quantity meters, and by transducers that yield a frequency output corresponding to the measured variable. Also, incremental digital shaft-position quantizers produce signals resembling analog pulse-time since the duration of the output pulses is not restricted to discrete time intervals.

Matching coded data to the computer

Where a transducer can provide upon command a digital output of acceptable level in the computer code, matching this transducer output to computer input merely requires triggering the command signal at the proper time. Usually this ideal situation does not prevail and provision must be made for matching the timing and possibly the code of the transducer output to the computer input.

Figure 5 shows the circuits for handling three common types of transducer outputs. In Figure 5A the output of a parallel digital device, such as a contactor shaft-position pickoff, is fed through a multiple gate to a register. If the transducer output code is not the same as the computer code a conversion matrix can be incorporated in the register, but it is usually more economical to modify the transducer to match the computer. The gated input to the register prevents errors due to changes in transducer output during the read period. This assumes that the transducer itself incorporates an unambiguous arrangement that prevents erroneous signals from reaching the gate during transition periods[9, 12].

In Figure 5B a pulse-time-modulated transducer such as an echo-ranging device that is unable to operate on the computer time scale produces signals that are alternately counted and stored in one of

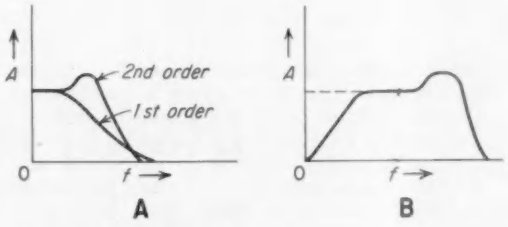


FIG. 6. Transducer response curves.
A. For first-order (such as a temperature sensor) and second-order (such as a spring-coupled displacement sensor) systems.
B. For a piezoelectric accelerometer and similar devices

the two counter registers. Two registers are required to prevent erroneous signals caused by changes in the count during a readout period. Timing signals derived from the transducer output cause gates *A* and *B* to operate so that the count is stored alternately in registers I and II. The same timing signals enable *C* and *D* in the opposite sequence so that the nonactive register is always available for readout. A simpler system may be satisfactory if it is permissible for an occasional erroneous reading to reach the computer, or if it is possible to synchronize the computer with the transducer or vice versa.

Figure 5C shows the circuitry that is necessary when the transducer puts out a pulse for each incremental increase in input. Outputs *A* and *B* are identical but are arranged to be 90 deg out of phase relative to the transducer input position. The two outputs and the gates, inverters, and reversible counter are necessary if counting is to be done in either direction. The circuit beyond the counter is similar to the parallel system of Figure 5A. Note that the incremental counter circuit requires continuous operation—momentary power failure causes loss of the zero reference if the input changes during the off-time, even though the register is nonperishable.

Signal spectral probability

Transducer response depends on how it is coupled to the process as well as on transducer characteristics. Mechanical-displacement sensing devices can be rigidly fastened to the moving member whose position they are to measure without any effect on system response other than a slight increase in the mass of the moving member. If the transducer is coupled by means of an intermediate elastic member, it will have the response of a second-order system as shown in Figure 6A. The temperature-sensing element discussed earlier has approximately a first-order response, also shown in Figure 6A. A device that has the characteristics of a second-order mechanical system but which is not directly coupled electrically to the output responds as shown in Figure 6B. An example of the latter is a piezoelectric accelerometer, which may have an essentially flat response from 20 to more than 10,000 cps.

Figure 7A shows a typical spectral probability curve for direct output devices. The shape of an actual curve depends on the input spectral distribution, the significant points being that very little information lies to the right of the transducer natural frequency f_n, and that a bandwidth of about twice this fre-

quency is adequate for transmitting this information without noticeable loss. There is no difficulty in designing suitable bandwidth amplifiers (buffers, line drivers, etc.) for signal amplification. This is usually also true for modulated carrier devices such as differential transformers, synchros, etc., which have a spectral distribution similar to that shown in Figure 7B. When the carrier frequency is above the audio range it is advisable to use tuned amplifiers, since they are capable of more gain per stage and single tuned circuits yield adequate bandwidth.

Impedance matching

Certain transducers, such as piezoelectric accelerometers and force pickoffs, capacitive pickoffs, photocells, resistive humidity sensors, pH meters, and ionization cells present special impedance matching problems. If long-term drift can be tolerated, cathode followers can be used to match high-impedance devices to lines up to several hundred feet in length. Usually the signals should be amplified to levels where the peak output is 100 milliwatts or more, since this minimizes the effects of low-level crosstalk. If the signal is dc it will probably be necessary to use an ac amplifier with modulation and demodulation. Many types of modulators are available for this purpose[16].

Filtering

Matching commercially available digital transducers to computing controllers is usually more a problem of encoding and readout (involving the techniques explained above) than signal amplification or conditioning. The exception is where very long distances are involved. Where amplification is necessary, noise buildup can be prevented by nonlinear circuitry, as shown by the waveforms and gain characteristic of Figure 8. Note that an amplitude margin must exist or spurious output signals will be produced. More sophisticated filters can be used, but a cheaper solution is to maintain an amplitude margin sufficiently large to avoid the need for additional filtering.

Note that despite the use of nonlinear amplification there is some uncertainty as to the exact timing of the leading and trailing edges of the pulse. The finite slopes at these points are particularly noticeable when the noise voltage resulting from long-distance transmission varies the instant at which the amplifier output changes value. All pulse circuits exhibit this jitter to a greater or lesser extent and a certain amount can usually be tolerated by a computer.

If noisy amplitude-modulated signals are to be converted to digital signals, it is usually best to filter in the analog form before encoding. If the noise has a constant power-density spectrum (white noise), the frequency response of the filter can be selected to match the probable spectral density of the signal. If it has other characteristics, it may be possible to apply statistical design principles to the selection of a suitable filter.

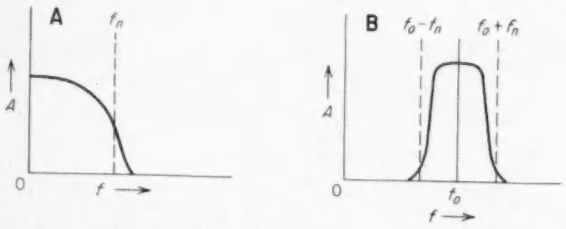


FIG. 7. Spectral probability curves.
A. For direct output devices.
B. For modulated carrier devices.

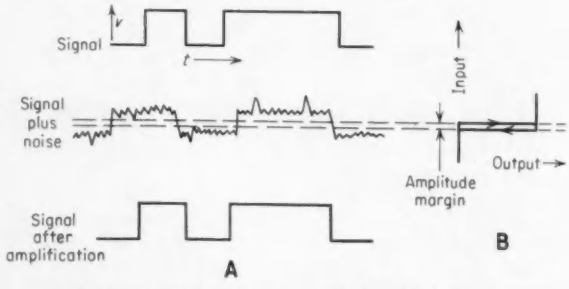


FIG. 8. Nonlinear amplification of digital signal to prevent noise buildup.
A. Signal waveforms before and after amplification.
B. Characteristics of nonlinear amplifier.

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From Controller Output to Process Actuation

JOHN M. SALZER, Magnavox Research Laboratories

THE GIST: The preceding articles in this issue deal with information handling—the problems of obtaining low-level signals proportional to process variables and combining and manipulating these signals in a computing controller to generate output commands. But from this point on, power must be handled as well as information, because the output commands must be amplified to a level capable of effecting process changes through actuators. It soon becomes apparent that accuracy and high power present somewhat conflicting requirements, and, indeed, one of the major reasons for using closed-loop systems is to place the burden of precision on low-power measuring devices and avoid the necessity of calibrating high-power effectors.

Although the emphasis here is on joining a computing-controller to a process, the techniques are those of any control system: transmitting the controller output command to the vicinity of the process, possibly converting it to another form amplifying it, and applying it to an actuator to effect process changes. Author Salzer treats these points, starting at the actuator and working back to the controller.

A typical link connecting a computing-controller to a process is shown in Figure 1. The output command is in the form of an electric signal, amplified and converted to a mechanical displacement. This displacement is the input to a hydraulic amplifier whose output is finally powerful enough to drive the actuating valve. As power is added at each stage of amplification, it is difficult to maintain the proportionality factor without appropriate feedback loops. It is true that the process variable measurement is fed to the controller, but the time constant around the whole system is likely to be too long to produce a corrective command in time. Therefore, it is essential to incorporate feedback loops around the various stages of amplification to counteract signal degradation as power is added.

Besides amplification, signal *conversion* and *transmission* are also performed in the link between the controller and the process. The order of these functions depends on the specific application, and the functions themselves are often intermixed. Signal conversion may occur during amplification, and either of these actions may take place at various points in the transmission link. Sometimes not all of the functions are necessary.

The power level of measurement and computation is usually unimportant, the primary concern being the information content of the signals. In the link between the computing-controller and the process however, the power level becomes a design objective. The signal appearing at the output of the controller can be likened to a trigger that controls the release of power (amplification) at the proper place (transmission) in the proper form (conversion).

The controller-to-process link can take a variety of forms depending not only on the process and the controller, but also on practical considerations and on the designer's imagination. The following discussion, starting at the actuator and working back to the process, covers some of the components and techniques that can be used in this link.

Actuation

Considering the tremendous variety of automatic industrial and military processes, it is surprising to find only a limited number of basically different actuating mechanisms. The whole gamut of final process variables—temperature, pressure, liquid level,

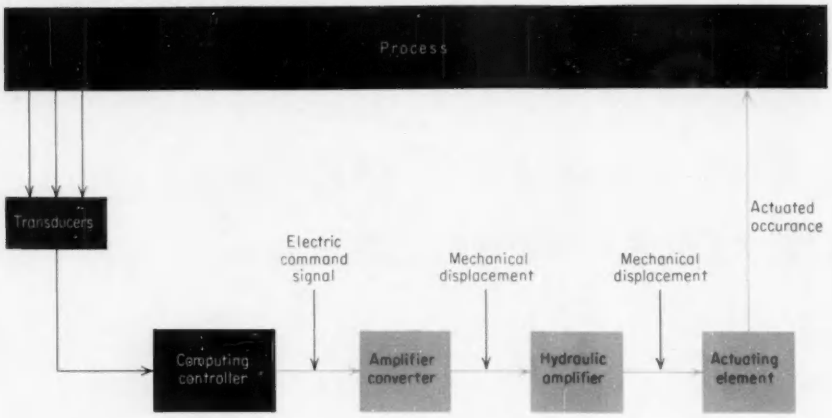

FIG. 1. Joining the computing controller to the process.

flow rate, machined shape, humidity, weight, alkalinity, etc.–can be controlled by a liquid flow, a linear or angular displacement, or a rate of displacement. As flow is regulated by the motion of a valve or pump, so the final controlled output is a movement or rate of movement of an actuating element (the valve stem or pump shaft). The only obvious exception occurs when electric power is modulated, and even here the final control is often through a displacement.

Liquid or gas flow is the means for controlling a host of chemical and physical processes. For liquids under pressure, valve motion can act as the passive actuating element. Figure 2 shows three common valve configurations. The diaphragm-operated valve is suitable for controlling the flow of high-pressure fluids, the operating medium–air or oil–moving the diaphragm. Continuous control electrohydraulic and all-electric valve actuators are also now available. The valve opening area can be made proportional to diaphragm motion or to an arbitrary function of it (see Reference 1, pp. 84-98, and Reference 2). For on-off duty a valve can also be solenoid operated. Butterfly or louvered valves are usually used to control the flow of gases at moderate pressures, although some models of butterfly valves are available for high-pressure liquid service.

Pumps can be used to actively control flow, Figure 3. Gear and piston pump operation requires no explanation. The vanes of the vane pump slide in and out of the rotor, sucking liquid in, then scooping it around, and pushing it out the other side. All three types of pumps normally have a fixed displacement, so that flow rate can be varied only by changing the speed of the prime mover. Variable-displacement piston pumps are also widely used.

Electric motors are most widely used for controlling displacement and speed. Positioning the work and cutting tools on a machine tool, controlling register for multicolor printing, maintaining proper rolling speed on a mill, and tracking a target by radar are only a few of almost innumerable applications. For high accelerations or where sudden full-speed operation is required, a constant-speed motor can be clutched to the load. Proportional clutches and couplings such as eddy-current or magnetic-particle clutches and certain types of fluid couplings can be used for continuous control.

Where linear displacements involve large forces and high performance requirements, hydraulic or pneumatic cylinders are usually preferred as actuators because of their direct linear-motion output and their compactness and high response characteristics. Rotary hydraulic motors similar to the pump types of Figure 2, and limited motion rotary hydraulic actuators are being used in high-hp. systems for the same reasons[4].

In some processes, actuation is by the controlled flow of electric power rather than by mechanical motion or fluid flow. Temperature control by electric current is a good example. In resistance welding, current is regulated in conjunction with work movement.

Amplification

The command signal generated in a computing-controller may require conversion to the correct form as well as several stages of amplification before it can actuate the final mechanism. Both conversion and computation may take place during amplification; that is, an electrical signal may be amplified and converted to mechanical form, or integration and similar transfer properties may be incorporated into the amplifier.

On-off control is the simplest form of amplification. A low-power signal can energize a relay capable of handling a much higher power level, and relays can be easily cascaded to achieve very high gains. Mechanical and magnetic clutches will operate on much lower levels of energization than the mechanical energy they can transmit. Solenoid-operated valves can cause sudden changes in flow or pressure. Note also, that the solenoid as well as the magnetic clutch convert one form of energy to another.

Electronic amplifiers, both tube and transistor, are used extensively to raise the level of the controller output signal to a power level capable of operating large relays, solenoids, electric motors, or generators. Ac amplification is most widely used because of the drift problem in electronic dc amplifiers. In an ac servo system, the magnitude and sign of the signal quantity are generally represented by the amplitude and phase of the ac waveform. In low-powered systems (under a few hundred watts), the ac signal may be fed directly to the control winding of a two-phase servomotor. Dc amplification is often circumvented by ac amplifiers, modulating the dc input and demodulating the ac output.

An important type of electronic amplifier uses gas tubes for greater power amplification. The three-

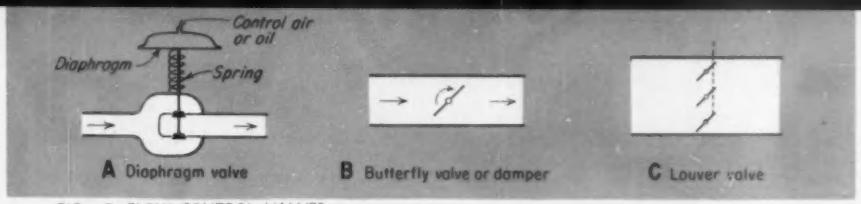

FIG. 2. FLOW CONTROL VALVES

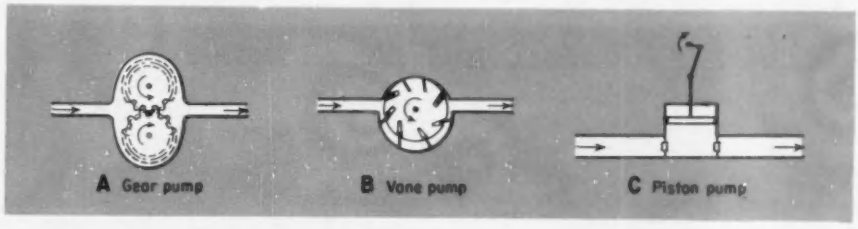

FIG. 3. FIXED-DISPLACEMENT PUMPS

element thermionic gas tube, the thyratron, can be used in circuits supplying as high as 40-amp peak currents (see Reference 4, p. 80, and References 5 and 6). If an ac voltage is applied across the plate and cathode of a thyratron, the tube will "fire" (start conducting) when the grid becomes positive during the positive half-cycle, and "extinguish" (stop conducting) at the end of this half cycle on the plate. By controlling the phase of an ac signal to the grid or by controlling the dc bias on the grid, a thyratron can be made to fire at any time during the positive half-cycle on the plate. This technique, which varies the average of a pulsating direct current, is widely used in many dc motor speed control systems, Figure 4. Thyratron circuits are also used to control the ignitor (trigger) of ignitron tubes. A mercury-arc device, an ignitron can supply peak output currents up to thousands of amperes (see Reference 4, p. 81) and is often used as the final stage in welding-control and speed-control systems.[7]

Where reliability and the ability to withstand shock and vibration are essential, magnetic amplifiers are often preferred to electron-tube amplifiers. Magnetic amplifiers modulate the flow of ac power in accordance with a dc control input. Their output is usually rectified to provide suitable signals for the next circuit or for integral compensating winding. The dc signal applied to the signal windings affects the degree of saturation of the magnetic core, varying the impedance of the ac winding and controlling the alternating current output to the load. The size and the response time of magnetic amplifiers decrease at higher operating frequencies, so that 400-cps ac supplies are usually used in preference to 60 cps. Temperature limitations are being overcome by the development of improved core materials.

Electromechanical rotating amplifiers are used in high-power applications. A generator can deliver 20 times the power required to excite its field windings. Two generators can be readily cascaded but such a combination has poor response characteristics. The amplidyne is a rotating machine that can be thought of as two cascaded generators in one frame. It is smaller, however, responds faster, and is capable of greater power amplification. Power gains vary from 700 to 100,000 (see Reference 8, p. 184) and current gains from 300 to 2,000 (see Reference 4, p. 427).

Even more important than the rotating amplifiers are the electric motors that amplify electrical power and at the same time convert it to mechanical form. The most widely used ac servomotors are of the two-phase induction type. These units have a main field winding energized from a constant reference supply, and a control field in space quadrature to the main field. The input to the control winding is 90 deg out of phase with the reference supply; the direction of rotation depends on whether the control signal leads or lags, while the speed of rotation depends on the magnitude of the control signal. A typical two-phase servomotor has a nearly straight line speed-torque curve of negative slope, which means that the highest torque is available at stall and internal motor damping is approximately constant over the whole speed range. However, these motors are inefficient in the larger sizes; consequently, dc systems are used when the power required is over a few hundred watts.

The thyratron control of dc servomotors has already been briefly covered. In the output-position/input-voltage transfer function of an armature-controlled dc motor, there is an integration term (because motor speed varies with armature voltage), and usually a lag term (resulting from motor inertia and damping). Another lag term is often present in the transfer function of an ac servomotor because of the effect of winding inductance. In positioning applications, the integration term assures zero steady-state error, the positioning accuracy being dependent on the accuracy of the low-power displacement transducer.

Hydraulic amplifier output-position/input-position transfer functions also have an integration term, and this is acompanied by a damped oscillation term rather than by a sample lag. With hydraulic amplifiers, simple mechanical feedback will yield an output displacement proportional to input displacement, Figure 5. If the control valve is moved slightly to the left, high-pressure oil is passed to the left-hand end of the ram cylinder, pushing the ram piston to the right. If the follow-up link were not connected to the piston rod, the latter would continue to move to the right at a substantially constant velocity, demonstrating the integrating action noted above. With the followup link connected, however, the sleeve is moved to the left until the inlet and outlet oil passages are blocked. The proportionality factor relating input to output motion depends on the position of the feedback link fulcrum.

Hydraulic systems are efficient, extremely compact, fast, and are capable of high torque outputs, but all

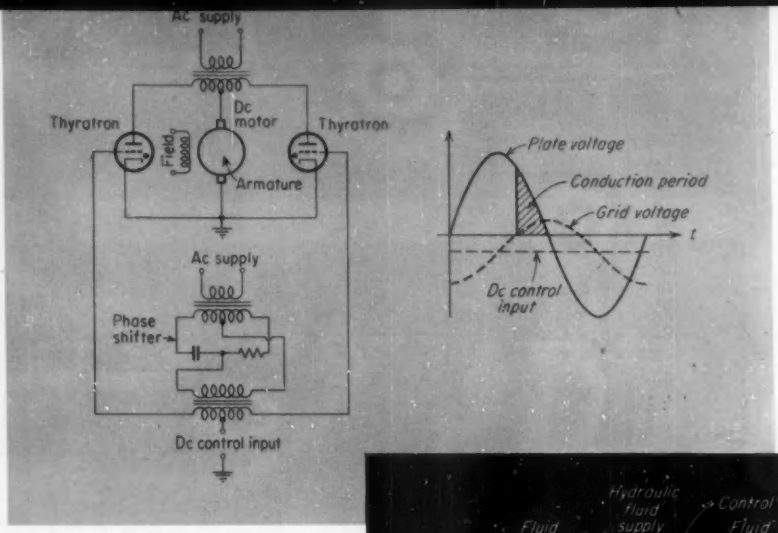

FIG. 4. Thyratron full-wave amplifier for unidirectional speed control of dc motor.

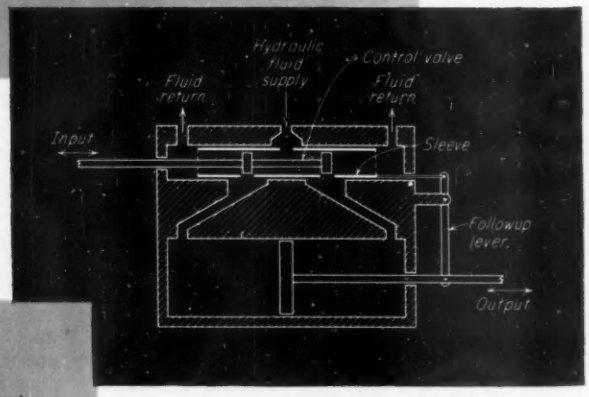

FIG. 5. Valve-and-piston hydraulic amplifier.

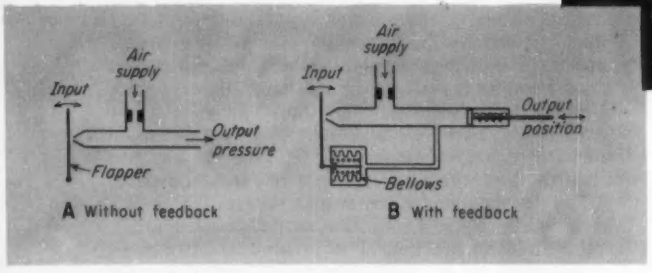

FIG. 6. Flapper-nozzle pneumatic amplifiers.
A. Without feedback.
B. With feedback.

high-pressure liquid-powered systems have the annoying and sometimes overpowering problems of leakage, transmission, filtering, and trapped air. However, hydraulic systems are unmatched where specifications call for high torque and small size. Aircraft control surfaces and gun mounts are generally driven hydraulically, and so are many new military and industrial systems. The hydraulic amplifier of Figure 5 is but one of many types. In another approach to hydraulic amplification, the power output or flow rate of a constant-speed variable-displacement pump is varied by changing the pump stroke[3]. Often the stroke-changing input motion comes from a preceding stage of hydraulic amplification (Figure 5).

Hydraulic and pneumatic amplifiers that use the flapper-nozzle technique are available. As shown in Figure 6A, output pressure (or volume) depends on the position of the flapper controlling drain through the nozzle. Many electrohydraulic servo valves and pneumatic controllers use this device.

If the output of a pneumatic flapper-nozzle amplifier drives a piston, the latter's speed is proportional to input flapper position. This is another illustration of the integration effect, already noted in connection with electric motors and hydraulic amplifiers. However, piston or diaphragm motion is usually opposed by a spring, as in the valve of Figure 2A. Here pneumatic and spring forces balance to establish output position, presenting an open-loop calibration problem. Figure 6B shows a feedback arrangement that aids in fixing the output pressure. The bellows measures the output pressure and produces a motion that subtracts from the input.

Signal conversion and transmission

The actuator and final stages of power amplification must, of course, be near the process, but the computing controller may be some distance away. And if it is, the command signal can be transmitted by techniques identical to those discussed in the preceding article. But regardless of the way the transmission is accomplished, the output of the computing-controller must be made compatible with the amplifier input requirements. Often conversion and amplification occur at both ends of transmission.

An analog computer is likely to generate a mechanical position or an ac or dc signal as the analog of the computed command. A mechanical displacement can be directly applied to hydraulic or pneumatic amplifiers, but must be converted if electronic or electrical amplifiers are used. A potentiometer (resistive, inductive, capacitive, etc.) is an obvious way of converting a shaft position to either an ac or dc signal, although

linearity and resolution may present problems with certain types of pots. Ac voltages proportional to the sine of a shaft angle can be produced by resolvers and synchros. Rectilinear inductive devices such as the linear differential transformer are useful for converting straight-line motions.

After amplification, ac or dc signals can be converted to mechanical displacements by means of solenoids, torque synchro receivers, or torque motors. Ac signals are more easily transmitted, and for this reason dc signals are often modulated before transmission (both types of signals may be converted to digital form for telemetering over long distances). At the receiving end, a servo amplifier minimizes the loading effect on the transmitted signal.

Where the computing controller is digital, the conversion and transmission techniques are usually decidedly different. Of course, the digital command signal can be immediately converted to analog form so that the techniques described above can be used (except for added necessity of storage or interpolation), but this approach may not be the most efficient, particularly when data transmission is involved.

The output of a digital computer is a periodically calculated numerical result—it is in digital form and it is sampled. Thus there are two stages in making such a signal compatible with the amplifiers and actuators of a control system: conversion to analog form, and interpolation from sample to sample.

Most general-purpose digital computers and some special-purpose ones calculate a new full value of the output variable during each computing cycle—so-called absolute computation[9]. Figure 7A shows a straightforward way of converting such a full digital value to a dc voltage. The digital output command is held in a register, each digit of which controls appropriately weighted currents or voltages. Summing these signals yields a dc voltage proportional to the number. If the data is to be transmitted, it would probably be in digital form prior to conversion.

The interpolation or storage of data between computed samples is accomplished in the digital register, a very expensive piece of equipment. The high cost and attendant complexity of associating a separate digital storage device with each output variable often leads to time-sharing the register and conversion network between several output commands, Figure 7B. Here, a relatively simple capacitor-amplifier combination provides interpolation or storage for each data channel in the analog form.

Figure 7C shows an entirely different philosophy of conversion. At each sampling instant the digital counter is filled with the command signal from an absolute computer. A constant-frequency pulse source is then used to count down to zero, producing a number of pulses equal to the size of the sample. These bursts of pulses are converted to proportional time intervals, and averaging this waveform gives the desired proportional voltage. If necessary, any one of the forms—the original sequence of digits, the pulse packs, or the width-modulated pulses—can be transmitted.

One way to obtain a shaft position proportional to a number is to use the output of the conversion method shown in Figure 7A as the input to a conventional analog servo. Another way is to use a digital servo, Figure 8. The serial digital subtractor yields the digital difference between the new computed sample and the digital representation of actual shaft

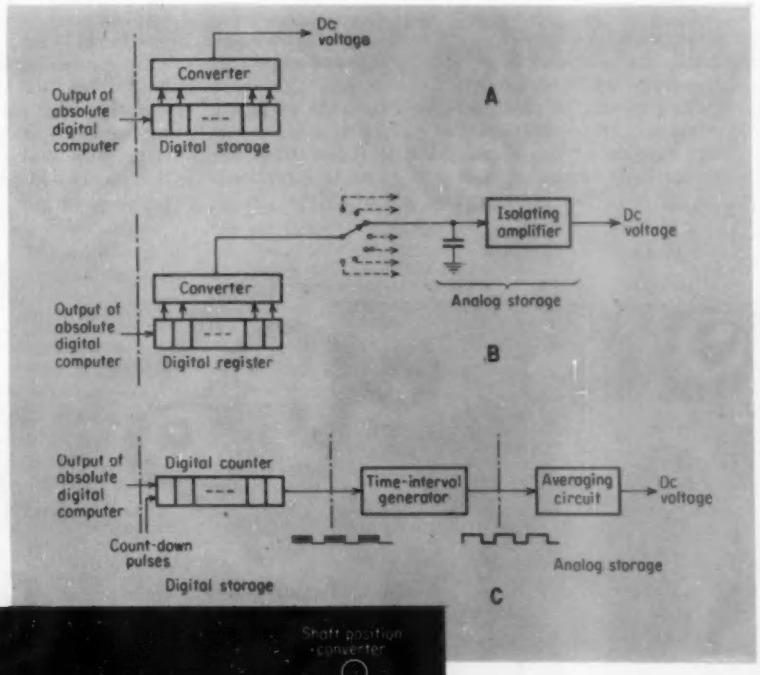

FIG. 7. CONVERTING FULL-VALUE NUMBERS TO DC VOLTAGES
A. Usual digital-to-voltage conversion.
B. Time-sharing of conversion equipment.
C. Digital-to-time-to-voltage conversion.

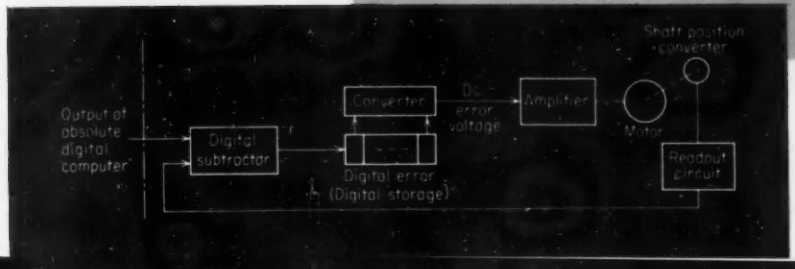

FIG. 8. Converting full-value numbers to shaft position.

position. The digital difference need only consist of a limited number of digits, and the conversion device can be rather crude since it only affects the servo loop gain. As long as the loop is stable, the static accuracy of the system depends on the precision of the shaft-position converter.

Another digital computer—the incremental type—computes only the change in output during each cycle. Digital differential analyzers belong to this class. The ternary incremental computer permits a positive, negative, or zero change in any quantity, but even simpler arithmetically is the binary (also called dinary) system, which is biased so that a positive increment is represented by a pulse, a negative increment by the absence of a pulse, and a zero increment by a pulse in one cycle and none in the next. In any case, binary-to-ternary conversion is simple.

To obtain a dc voltage proportional to the full value of the output, the increments are first accumulated in a counter as shown in Figure 9A and then converted by one of the methods shown in Figure 7. In another conversion technique, Figure 9B, a standard pulse is formed for each increment and the pulse areas stored in an analog integrator. This technique can be used with either ternary or binary increments, since the proper bias can be restored in the integrator. System accuracy depends on the integration and on how precisely the area is held under a standard pulse. Slow drifts may be permissible where the conversion chain is part of a sufficiently tight feedback loop.

One of the most direct ways to obtain a shaft position from the output of an incremental computer features a notching or stepping motor[10]. As shown in Figure 10A, each amplified pulse steps the motor one, and only one, increment in the proper direction. As an alternate technique, Figure 10B, a continuous motor can be servoed in steps. Incremental changes in motor position and the direction of these changes are sensed and subtracted from the corresponding incremental commands. A short two-way counter tracks the positional error, and a crude converter tells the motor which way to run and how fast.

In a third type of digital computer—the pulse-rate computer—the average rate of a pulse train represents the variable of interest. This type differs from the incremental computer in that the rate of increments or pulses in the latter is proportional to the rate of change of a quantity rather than to the quantity itself. The conversion scheme of Figure 11A gates the pulse train over a fixed period, yielding a count that represents the average pulse rate. This full-value number is then converted to a dc voltage by one of the methods already discussed. While the counter is cleared and used for the next count-up, the dc voltage is stored by analog means. Figure 11B shows another conversion technique. This one is not completely satisfactory because the pulse rate is often quite irregular, making it difficult to generate sinusoidal waves, and the frequency discriminator has to contend with a wide range of frequencies.

Power sources and distribution

Amplification is the controlled release of power. For the amplifiers discussed here, power must be available in electric, hydraulic, or pneumatic form.

By transmitting and distributing electric power, whole systems can be supplied from a central source. In an aircraft electric system, for example, 400 cps, three-phase ac and several levels of dc are available for use anywhere in the plane. The electric power for a processing or manufacturing plant comes from a custom-tailored system utilizing ac and dc voltages at various levels. It is often converted to dc right at the point where the dc is to be used. This can be advantageous because of the efficiency of transmitting ac and the availability of high-quality rectifiers. The same is true of 400-cps ac when it is required for industrial systems. As other forms of energy are required in various locations, they are generated from electric power.

Hydraulic power is usually generated at the point of use by electric-motor driven pumps. These may be constant-displacement constant-speed pumps generating power for several actuating functions, or variable-displacement pumps for the direct control of a single function. Where distances are relatively short, a centrally located pump may be used and the high-pressure fluid distributed through piping. Pressures up to several thousand psi are common. However, while oil is essentially incompressible, piping expansion and trapped air lend a compressibility effect to the system that causes additional damping and lag. The practical problems of oil filtering and pressure-tight fittings

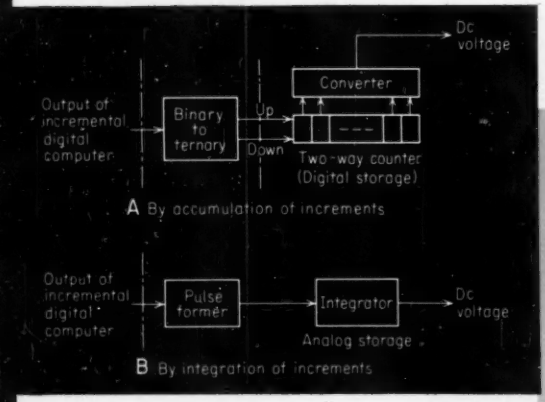

FIG. 9. CONVERTING INCREMENTAL DIGITAL VALUES TO DC VOLTAGES
A. By accumulation of increments.
B. By integration of increments.

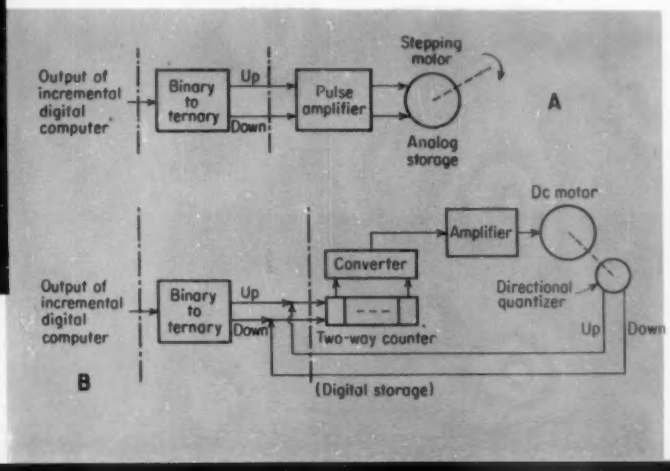

FIG. 10. CONVERTING INCREMENTAL DIGITAL VALUES TO SHAFT POSITION
A. Open-loop method.
B. Closed-loop method.

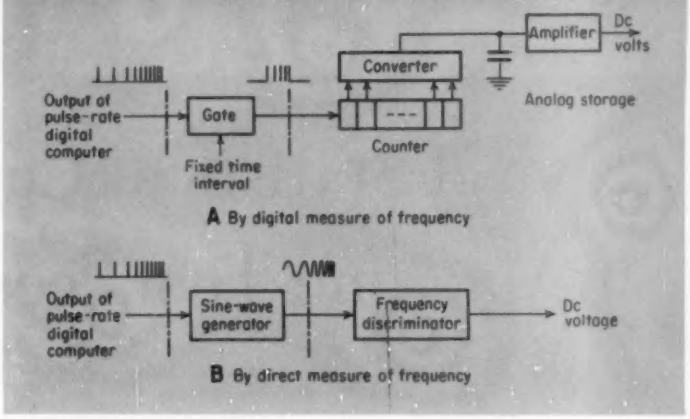

FIG. 11. CONVERTING PULSE-RATE DIGITAL VALUES TO DC VOLTAGES
A. By digitally measuring frequency.
B. By directly measuring frequency.

must also be considered by the designer—the hazards caused by leaking oil are often intolerable.

In pneumatic installations, central compressors usually supply a complete plant or system. This is because the problems of air filtering and vapor content reduction by cooling and draining make individual compressors impractical at the points of use. Since air is highly compressible, distribution systems using large amounts of tubing or piping have little effect on this variable; however, if high flow is required, pressure losses can be substantial. Actually 30-to-40-ft lengths of tubing help damp out oscillations (see Reference 1, p. 215). Pressures in industrial pneumatic supply systems range from 50 to 100 psi.

Safety is an important consideration in the selection and design of power systems. Designs should be fail-safe so that power interruptions cannot cause equipment damage or personnel injury. A valve that controls the flow of dangerous chemicals should be normally closed, so that loss of control air pressure will leave it closed. A gun barrel should not drop from its elevated position if a hydraulic power supply fails. These are obvious precautions and are instrumented by elaborate interlocks, electrical and mechanical, which are incorporated into the power supply system.

Design hints

Power efficiency and signal accuracy must be considered in choosing a signal and power system. Since the power requirements for actuation are often quite high, efficiency becomes an important economic consideration. So does the static accuracy of specific components, which must be compatible with signal requirements. The development of new components may sometimes be justified.

In cases where the computing-controller trims a conventional process control system, the command signal from the computer may represent a required change in set-point on a conventional electronic or pneumatic controller; for example, it may indicate a new controlled level of temperature, pressure, or flow. Since the set-point of many conventional controllers can be changed by means of a shaft rotation, a low-power-level electric-input/angular-position-output servo can usually be used to make this adjustment in accordance with the command signal.

The importance of dynamic considerations varies from application to application. The controller-to-process link is part of the major loop of a feedback control system, and as such, may seriously influence the operation of the whole system. In processes having long time constants, such as chemical processes, the delays and lags due to transmission, amplification, and actuation are often negligible, so that a simple dimensional gain constant can satisfactorily describe the elements of the link. In processes having short time constants or high natural frequencies, such as flight control systems, the specific characteristics of the command-to-process link become extremely critical and dynamically inseparable from the design of the whole system. The specific transfer function of each element in the link must be carefully considered in the system analysis, and certain ones may have to be modified and adjusted during the iterative steps of the design procedure. Even more difficult is the problem of appropriate design for variable processes or for systems in which the limits of operation include saturation and other nonlinear effects in the forward link.

Though the basic idea of getting the computed command to the process is straightforward, its realization is often an elaborate engineering task. Feedback-control theory, power-engineering practice, and complete understanding of the application must be combined to yield suitable results.

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Role of Statistical Computation in Machine-Tool Feedback Gaging

Increasing demand for 100-percent inspection in parts manufacturing has brought the statistical quality-control computer close to the feedback gaging loop. Described here is a mechanization of the statistical concept of "precontrol", wherein the Gaussian curve computed for a given application is designed directly into the circuit. Innovations include selective, rather than continuous, response and the use of statistical mathematics as criterion for process adjustment.

DAVID N. SMITH
Jones & Lamson Machine Co.

With the increasing emphasis placed on product quality through the years, the inspection station has moved steadily toward the point of manufacture. Although the customer was once the first who bothered to look for flaws, equal responsibility has long since been assumed by the manufacturer. And, even within the latter's plant, a shift can be noted—from the shipping room back to the machine tools that make the product components. In some of these machines, in-process gaging systems are working with feedback controls that adjust the tool settings to compensate for any tendency of the output to run out-of-tolerance.

Although feedback gaging is clearly a part of the science of quality control, most ventures into automatic feedback gaging have been made without attention to the mathematics of statistics, which have done so much to upgrade quality-control techniques to their present level and to give the designer an analytical basis on which to found the boundaries of his control. But there is evidence now that this situation is being corrected and that the statistical computer, either as an on-line part of the control loop or as an off-line design tool, will figure largely in gage controls. A description of one of the first applications, the stator-turning lathe of Figure 1, will demonstrate the main advantage of the statistical approach; control systems need not wait for rejects before initiating tool adjustment.

In the past, certain forms of automatic gaging have been widely employed in production operations involving discrete parts. Two well-established categories are typical of methods in current use. One, generally known as end-point control, has been applied frequently to cylindrical grinding. In this process a caliper gage rides continuously on the workpiece being ground. As the piece is reduced to the proper size, the gaging system monitors the dimensions, and as they approach the specified limits, triggers the feed-stop mechanism to interrupt the wheel in-feed. The second category is post-gaging, in which the part is measured after the dimension is produced. The control simply shuts down the machine when out-of-limit rejects are detected. This method is sometimes dubbed the "shut-off-and-yell" technique. The points of shut-down often are set somewhat inside the actual reject limits so that an approach toward, rather than an exceeding of, tolerance interrupts the process.

Recently there have been moves to obtain automatic gaging systems that will do much more than either of the foregoing. The objective is to develop controls that are capable not only of making measurements but also of using error detection or dimensional deviations to initiate corrective action. While such capabilities are immediately recognizable as those of a true feedback system, conventional feedback techniques are not fully applicable. This is because feedback is usually associated with continuous processes rather than with those involving discrete parts. Hence, certain basically new problems face the control engineer attempting to apply the principles of feedback to automatic gaging.

Normal dispersion

The first unique requirement is that the feedback control accept certain magnitudes of error without taking corrective action. The reason for this is that piece-to-piece variations are inherent in parts manufacturing. Indeed, if a gaging system has a high enough resolution, it will find that no two pieces coming off the machine are exactly alike. There is a normal dispersion in any process, and this is related to what the quality control engineer calls the "machine capability". This term describes the statistical spread of characteristics in the parts produced when the process is left to run unregulated, and when all the assignable causes of variation have been brought under control, leaving only those random causes that cannot be identified or are impractical to improve. In building an automatically regulated process of the discrete-part type, it is necessary that the machine capability be well within the allowed tolerance, preferably occupying no more than 50 percent of the tolerance range. Figure 2 shows a machine capability that satisfies this condition and provides sufficient latitude for practical control.

An examination of the statistical mathematics represented by the distribution curve of Figure 2 will help

in understanding the nature of the problem. A run of n pieces (50 to 100 pieces is a good lot size) is made without adjusting the process. If measurements of each piece are taken and plotted according to size distribution, the curve shown will be formed.

The bell-shaped plot in Figure 2 embodies one of the fundamental concepts upon which the science of statistical quality control is based. It is termed a Gaussian or normal distribution curve—"normal" because this type of distribution occurs so frequently in nature. If, for example, a large group of people was assembled randomly and each weighed, a plot of their individual weights (or heights, for that matter) would exactly follow the bell-shaped curve.

The normal curve provides a basis for determining how much of a deviation from the mean can be ignored by the control. The mean is the arithmetic average of the sizes of all pieces included in the distribution curve. The deviation for any particular piece is the amount by which its size differs from the mean. The most useful criterion for dispersion is the standard deviation represented by the symbol σ (sigma). With this criterion the control engineer can compare the efficiencies of two methods of production or evaluate the characteristics of one method under two different circumstances. To determine the value of σ for a set of five values, it is necessary first to compute the average of these values. For example:

$$\begin{aligned} X_1 &= 22.0 \\ X_2 &= 22.5 \\ X_3 &= 22.5 \\ X_4 &= 24.0 \\ X_5 &= 23.5 \\ \Sigma X &= 114.5 \end{aligned}$$

Then, the average value is

$$\overline{X} = \frac{114.5}{5} = 22.9$$

The standard deviation, or the root-mean-square deviation as it is sometimes called, is found by taking the square root of the mean of the squares of the deviations from the average value of the group:

$$\sigma = \sqrt{\frac{\sum_{i=n}^{i=1} (X_i - \overline{X})^2}{n}}$$

In the case of the above example, the standard deviation σ is calculated as follows:

$X_1 - \overline{X} = -0.9$	$(X_1 - \overline{X})^2 = 0.81$
$X_2 - \overline{X} = -0.4$	$(X_2 - \overline{X})^2 = 0.16$
$X_3 - \overline{X} = -0.4$	$(X_3 - \overline{X})^2 = 0.16$
$X_4 - \overline{X} = -1.1$	$(X_4 - \overline{X})^2 = 1.21$
$X_5 - \overline{X} = 0.6$	$(X_5 - \overline{X})^2 = 0.36$
	Sum of squares = 2.70

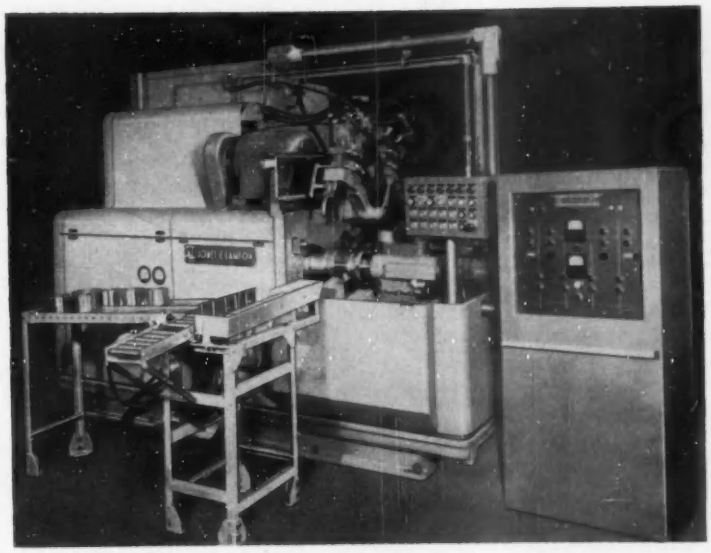


FIG. 1. Automatic lathe and gaging controls for machining electric motor stators.

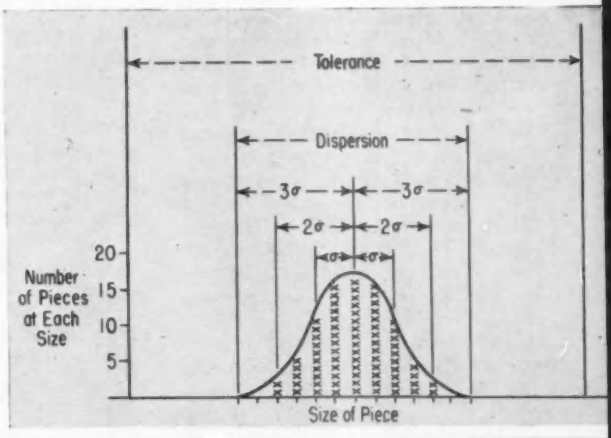


FIG. 2. Curve depicting distribution of dimensions of finished parts.

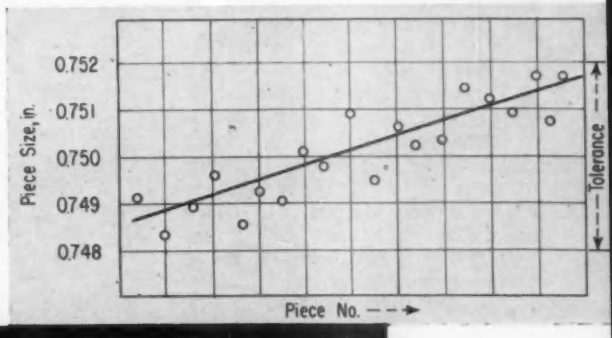


FIG. 3. Chart of piece measurements showing slow drift toward tolerance limits.

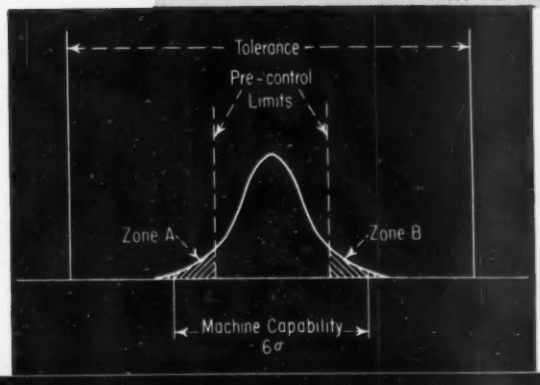


FIG. 4 Normal distribution curve with precontrol limits indicated.

Then, $\sigma = \sqrt{\frac{\Sigma(X_i - \bar{X})^2}{n}} = \sqrt{\frac{2.70}{5}} = 0.73$

The graph shown in Figure 2 is typical of any normal product output; there are, however, a number of processes that are affected by many nonlinear and intermittent variables. In such cases, the distribution curve would not follow the general appearance of the Gaussian pattern and might be considerably unsymmetrical. Statistical interpretation of such curves is difficult and beyond the scope of this article. Fortunately, the majority of parts manufacturing applications do exhibit normal curves. Thus, the control engineer can predict exactly what percentage of the parts can be expected to fall within any given dimensional range.

To demonstrate this, the area under the normal curve in Figure 2 has been divided into three sections. The first section includes all parts in a given production run whose dimensions are within the range extending 1σ on either side of the mean or zero ordinate. Assuming that the machine is operating normally, the area bounded by the 1σ and -1σ ordinates is found to be 68.26 percent of the total area under the curve. Stated another way, 68.26 percent of all parts produced should fall within a two-sigma range of deviation. Similarly, 95.44 percent comes within a four-sigma spread and 99.74 percent within a six-sigma spread. These figures provide a numerical measure of the process dispersion, useful for comparison purposes and for evaluating the improvement or deterioration in quality of product. It should be emphasized, however, that these values are applicable only when the process exhibits a normal distribution characteristic and is subject only to random disturbances.

Dimensional drift

The second unique problem in the design of a feedback gaging control for parts manufacturing is "drift", the relatively slow shift of characteristic with time caused by any reason whatsoever. Figure 3, a size-vs.-time plot of a process such as the stator-turning operation mentioned above, depicts the normal piece-to-piece scatter upon which is superimposed a slow drift out of tolerance. Such drift could be caused by machine temperature changes, tool wear, or similar long-time effects. Therefore, the system must be able to distinguish between the normal, inherent process scatter and the process drift, and react only to the latter.

Several solutions suggest themselves. One involves a computer which constantly recomputes the mean of the preceding, say 50, pieces by adding in the new measurement, dropping out the 51st piece previous, and then calculating a new mean value. While this could be a very precise solution, it would also be a prohibitively expensive one because of the extensive memory required and the rather sophisticated computation involved. A second approach might use the fact that there is in any process a certain statistical probability that a piece dimension will fall within a specific deviation from the mean. There is a high probability that it will fall near the mean, and a low probability that it will fall far from the mean, as portrayed by the Gaussian distribution curve. It is possible, therefore, to envision a computer-control that will examine each measurement according to this probability criterion, and make an adjustment proportional to the findings. But this, too, becomes complicated and expensive.

In the field of statistical quality control there recently appeared a new tool that employs go/no-go measuring techniques. Known as "precontrol", the method eliminates all on-the-job computation, the keeping of average and range charts, and the like, yet meets all statistical quality control requirements. It involves measuring each piece, but requires remembering only the value of the last piece measured. And it effectively distinguishes between scatter and drift.

The development of precontrol as a gaging and quality-control method was instituted to reduce the cost of applying statistical practices to production operations. The conventional techniques typically have been designed around probability theories of frequency and size of sampling vs. degree of risk in admitting faulty parts. They have necessitated measurement to a resolution one order finer than the specified tolerance, and the calculating and posting of "average-and-range" charts to detect drift. Generally speaking, the machine operator is not capable of carrying out such procedures. It is desirable, therefore, to reduce the quality control process to a simple go/no-go operation, with only the most elemental decisions necessary to dictate a process adjustment. An allied benefit of devising such a solution for the human operator would be the simplification of the automatic-gaging problem too, resulting in the most economical system.

The combined features sought in the ideal system are as follows:

(1) Ability to gage each piece, when finished, on a go/no-go basis, rather than measuring exact dimensions. With a human operator, it might be advisable to sample, but with an automatic system 100-percent testing is easily feasible.

(2) Ability to accept and ignore any normal deviation in the process, while recognizing shift and reacting properly to it with a process adjustment.

(3) Incremental correction, each step being sufficient in size to keep up with the expected rate of drift, but not so large as to over-compensate and throw the process out of control in the opposite direction.

(4) Need for only minimum memory capacity.

(5) Inclusion of appropriate logical action to protect as far as practicable against foreseeable accidental events.

Precontrol is so named because it permits a decision for corrective action to be made long before the process has deteriorated to the point that tolerances are exceeded and rejects made. The application of the precontrol concept to a given machine requires that the machine capability be well matched to the tolerance requirements. Figure 4 shows a desirable type of characteristic wherein the six-sigma spread, which can be expected to embrace 99.74 percent of all parts during a "good" run, is about 50 percent of the allowed tolerance. Thus, there is room for shift and correction without making rejects, an essential condition since any self-regulating system operates on error.

Once the machine capability and tolerance requirements are known, the precontrol limits can be determined. For any particular application, the precontrol limits are so computed that n successive pieces will occur in either zone A or zone B only if there is very high probability that the process has experienced a shift. By this built-in design, the system is enabled to separate scatter (noise) from drift (signal) with only enough memory capacity to store up to n successive pieces in either marginal zone.

The steps in the computation can be demonstrated with reference to Figures 5 and 6. In Figure 5 is a dispersion curve whose mean has shifted to the left of the original setting by an amount $\Delta m/\sigma$. (Note that here and in what follows Δm and W will be divided by σ to make their values dimensionless.) The shift is what happens to a process subject to drift, and the result is to increase the probability of n successive pieces falling in area A, and to decrease such probability in area B. For any given $\Delta m/\sigma$ these probabilities are cal-

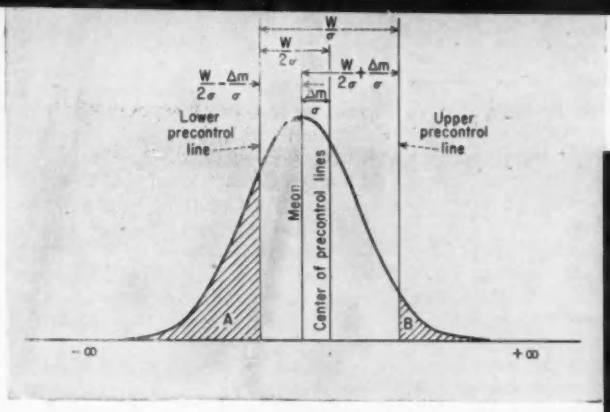


FIG. 5. Chart showing displacement of process mean from the center of the precontrolled lines and the resulting changes in areas A and B.

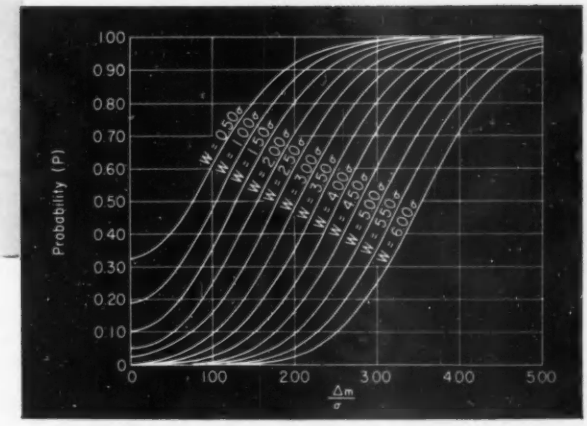


FIG. 6. Family of curves giving the probability of obtaining a feedback signal as a function of $\Delta m/\sigma$ for various precontrol spreads (W). Feedback signal occurs after two successive measurements on the same side of a precontrol line.

culable, and can be expressed by a family of confidence curves, as the spread of the precontrol limits (W/σ) and the shift of the mean ($\Delta m/\sigma$) are varied. A chart, such as that of Figure 6 for $n = 2$, can be used to establish the setting of the precontrol limits. For instance, if with $n = 2$ the precontrol limits are set at $W = 1.0\sigma$, a shift of 1.0σ in the process mean yields about a 50/50 chance for generating a signal to correct the setting. If the mean shifts 1.5σ, there is a chance better than seven out of ten for producing a corrective signal. How such a system is set up, therefore, depends on how much of the allowed tolerance is taken up by the normal process dispersion, what degree of risk of rejects is acceptable, and whether or not the drift tends to be always in the same direction.

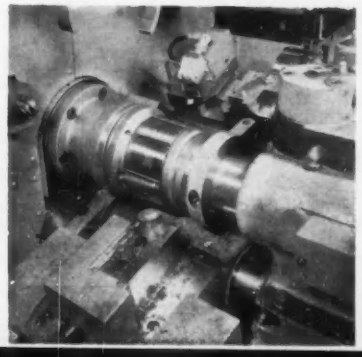
Machine-tool application

As was mentioned, the statistical quality-control methods discussed here have been successfully applied to an automatic lathe, Figure 1. This lathe is a special-purpose machine tool designed for an outside-diameter turning operation on electric-motor stators. Figure 7 shows a close-up view of a stator being machined.

An automatic loading mechanism moves the parts into and out of the lathe, the direction of flow being from back to front. The flat cylindrical tool seen on the tool block in Figure 7 is rocked into depth, then fed from right to left. After the part has been turned, a measuring head is brought in from the rear to check size. The gage head is of the magnetic proximity type whose pole faces are located above and behind the workpiece and are shaped to the curvature of the part. The tool can be adjusted toward the workpiece (to reduce size) or away from it (to increase size) by increments of 0.0002 in., and can be rotated by increments of 3.5 deg to make use of the entire periphery of the cutting edge. It is then turned over and, when the second side is worn out, replaced. Both in-and-out adjustment and rotation are accomplished by pulsed rotary solenoids.

There are several incentives for applying automatic "in-machine" gaging to this process. First, since the part is a stack of stamped laminations, it tends to go out-of-round when released from the fixture. Since the process can be regulated only for size, and not for roundness, the part should be gaged at a time when it is as round as it is ever going to be—while it is still on the fixture, just after machining. The gaging system then will not confuse roundness deviations with size deviations. Second, because the surface is interrupted by longitudinal welds that hold the stack together, out-of-machine gaging would bring up the problem of positioning the part to contact-gage on a land rather than in a slot. This problem does not exist when the part is checked while still rotating and without being touched by the sensing head. Another advantage of in-machine gaging is that it eliminates a separate inspection station. And, most important of all, it permits tightening the feedback loop for rapid response to current data. This reduces to a minimum the number of pieces in process between the point in the stream where correction can be applied and the point at which measurements are being taken.

FIG. 7. Close-up view of stator-turning operation.



System logic

The required logic for the system is displayed in Figure 8, not only for the gaging and regulating functions, but for all actions concerning part-quality control. Note that the "normal-dispersion" zone (the six-sigma process range) occupies about one-half of the tolerance spread. The total dimensional range is divided into five zones: mid-zone *A*, good; marginal zones *B* and *C*, still good but alerting the correction system; and reject zones *D* and *E* for undersize and oversize pieces respectively. Regarding the latter, it can be seen in Figure 1 that the receiving conveyor in front of the machine is also a sorter—good pieces are passed along to the next operation, but rejects are gated to one of two storage chutes (oversize and undersize) on the left.

In this application, the trend in the process is principally due to wear of the cutting edge of the tool, resulting in a tendency to run oversize. There is also the possibility of a sudden chip-out or flaking in the cutting edge, which might cause an oversize reject even if the regulating process is operating properly. Knowledge of such characteristics for the particular process enables the design of asymmetrical logic into the system, for appropriate action. In zone *C*, for example, there is scheduled the reset-

ting and indexing of the tool after 10 in-feeds. This number represents 0.002 in. of tool wear, a limiting amount based on experience. In zone *E*, a sudden oversize reject, very probably caused by the tool failure described above, dictates what action is to be taken. This action is different from that called for by the same type of reject in zone *D*, where there is no obvious and logical cause.

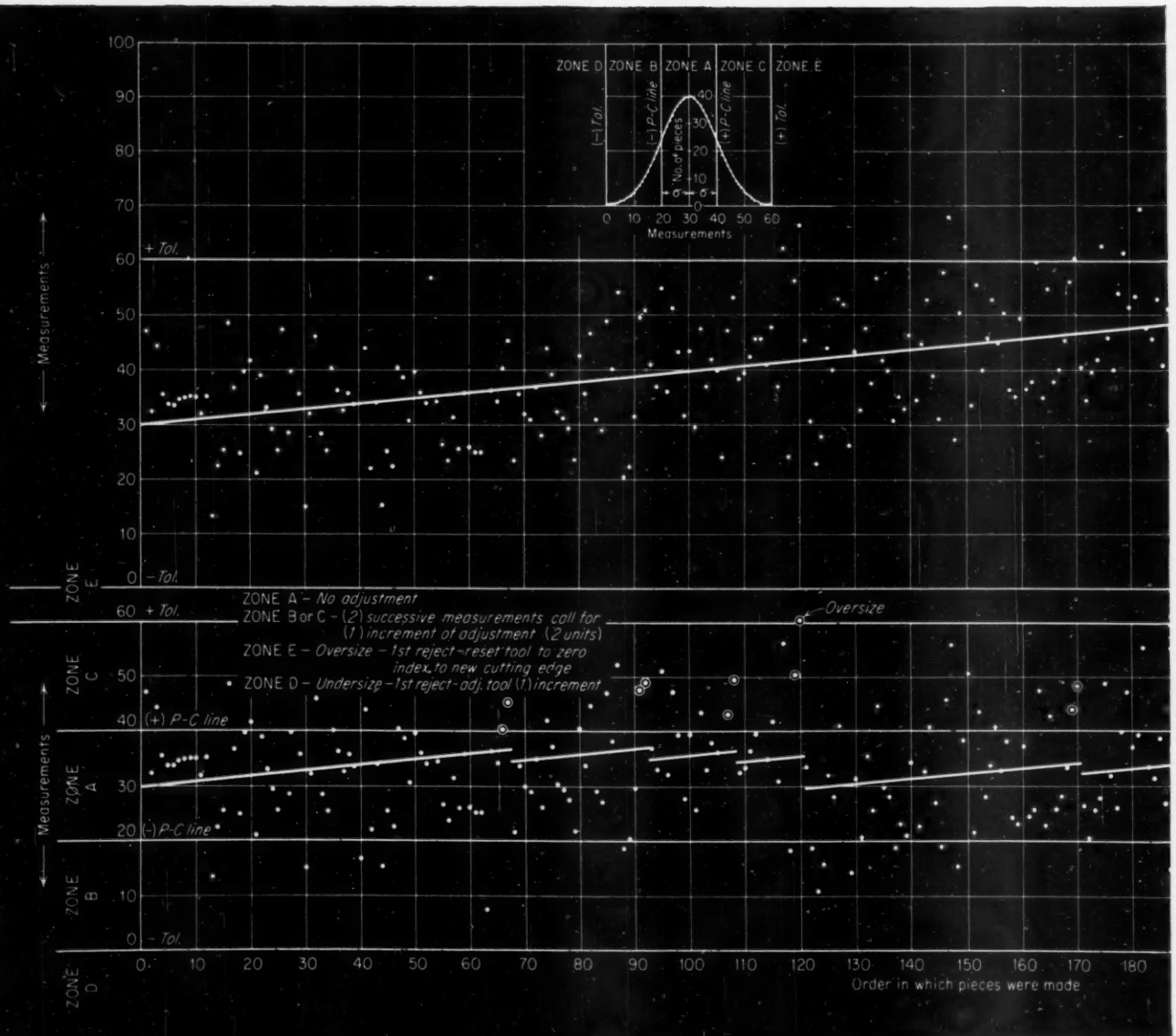
For easy understanding of the operating principles, this logic is reproduced on the panel of the regulating equipment, Figure 9. Both tolerance and precontrol limits are established by the setting of contact microammeters, with sensitivity adjustment for each. The number (n) of successive rejects allowable before a process adjustment is selected by means of a stepper-switch. The precontrol lines can be skewed for various conditions by biasing the settings of the contact meters. On this panel, therefore, are all the adjustments necessary to set up the system to meet a variety of conditions plus a visual display of the system functions.

Control circuit

The gaging circuit, Figure 11, is a comparison-measuring device, contrasting the reactance of the active gage head as it is affected by the size of the workpiece (magnetic reluctance of the air gap) with the constant reactance of a reference component. For the instant that point A is positive with respect to point *B*, current passes through discriminator rectifier 1 to capacitator C1. At the same time, current flows through gage-head rectifier 2 to C2. Both C1 and C2 will charge to equal voltages if the current through the gage head and the compensating reactor are equal.

On the next half-cycle, when point A is negative with respect to point *B*, current passes through C1, rectifier 3, and the gage head to point A. In addition, a current path is completed through capacitor C2, rectifier 4, and the compensating reactor to point A. Again, if the currents through the gage head and compensating reactor are equal, the voltages across C1 and C2 will be equal. Thus whenever equal currents flow on both alternate half-cycles, the net voltage across C1 and C2 is zero.

Assume now that the reactance of the gage head is less than that of the compensator, as it would be with an undersize part. In the first half-cycle (when A is positive), the current through C1 is less than the current through C2. Therefore, the voltage on C2 is higher than that on C1. In the next half-cycle, the reverse current through C1 is greater than the reverse current through C2. Capacitor C1 then has a negative voltage with respect to point *B* and C2 has a positive voltage. This sets up a current


ZONE D
ZONE B
ZONE A
ZONE C
ZONE E
(-) Tol.
(-) P-C line
(+) P-C line
(+) Tol.
No. of pieces
σ
Measurements
+ Tol.
- Tol.
Measurements
ZONE A – No adjustment
ZONE B or C – (2) successive measurements call for (1) increment of adjustment (2 units)
ZONE E – Oversize – 1st reject – reset tool to zero index, to new cutting edge
ZONE D – Undersize – 1st reject – adj. tool (1) increment
Oversize
(+) P-C line
(-) P-C line
Order in which pieces were made

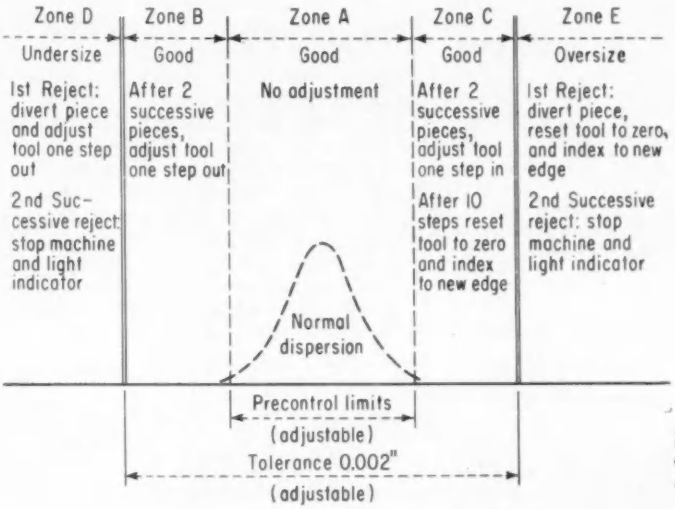

Zone D
Zone B
Zone A
Zone C
Zone E
Undersize
Good
Good
Good
Oversize
1st Reject: divert piece and adjust tool one step out
After 2 successive pieces, adjust tool one step out
No adjustment
After 2 successive pieces, adjust tool one step in
1st Reject: divert piece, reset tool to zero, and index to new edge
2nd Successive reject: stop machine and light indicator
After 10 steps reset tool to zero and index to new edge
2nd Successive reject: stop machine and light indicator
Normal dispersion
Precontrol limits
(adjustable)
Tolerance 0.002"
(adjustable)

FIG. 8. Schedule of machine logic based on both statistical methods (zones A, B, C) and machining experience (zones D, E).

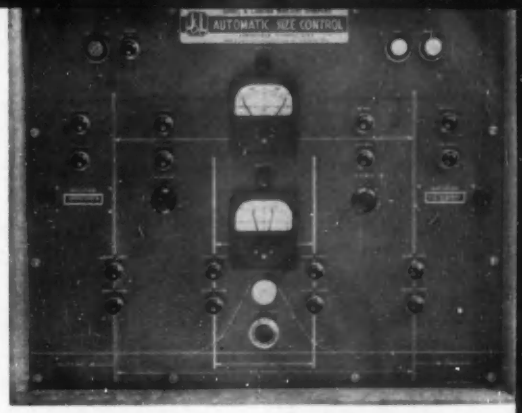
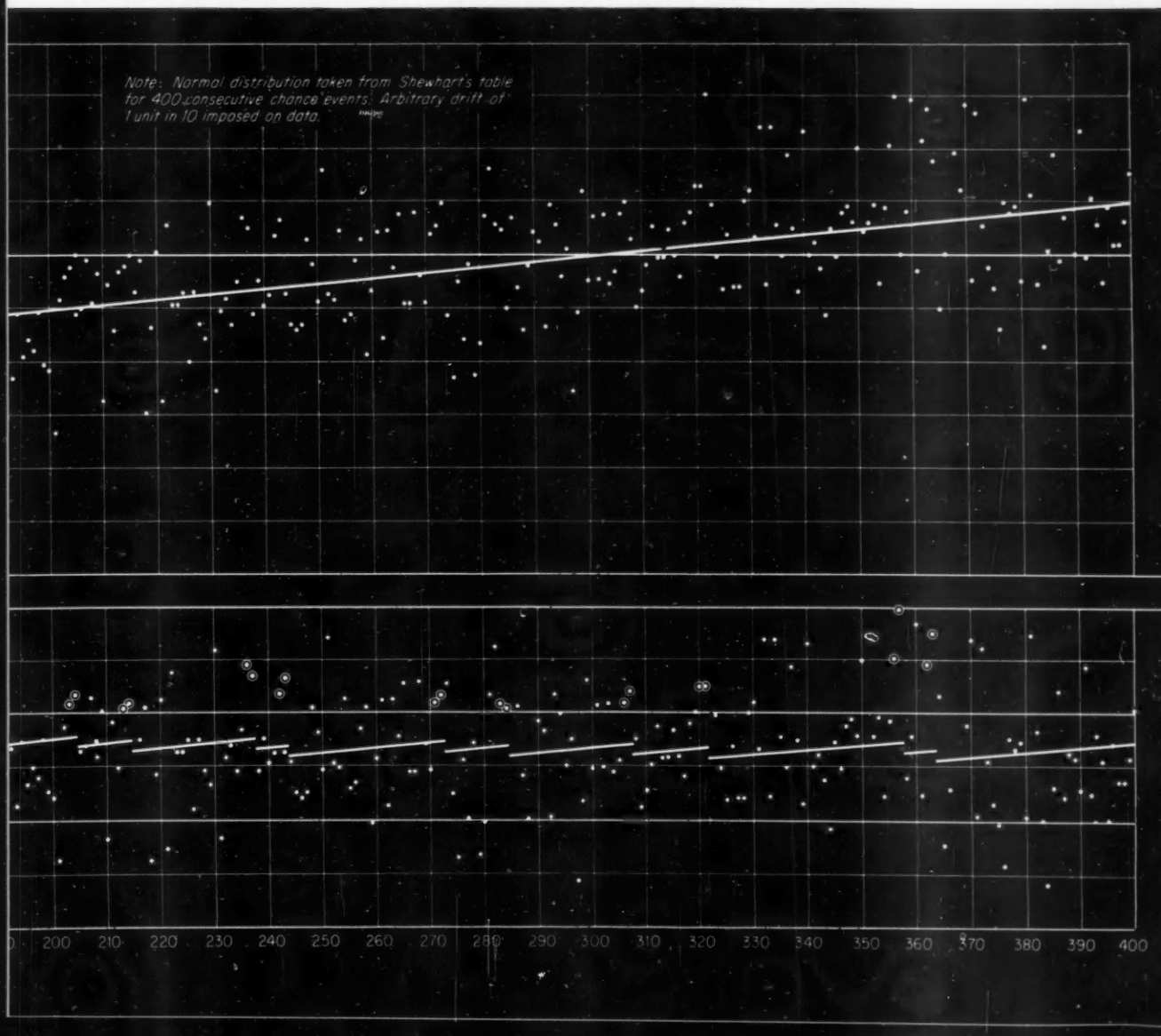


FIG. 9. Control panel showing adjustments and meter relays.

FIG. 10. Graphical method for determining relative effectiveness of any given statistical quality-control method. Field of points in part A is derived from table of random numbers, permitting the simulation of the output of a machine. Field has been arbitrarily skewed from the horizontal to feign the effect of drift. Part B shows same field with corrections after two successive rejects.



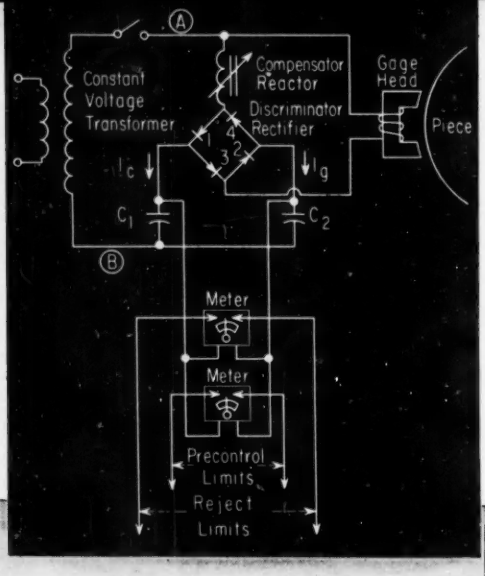


FIG. 11. *Schematic diagram of logical circuitry.*

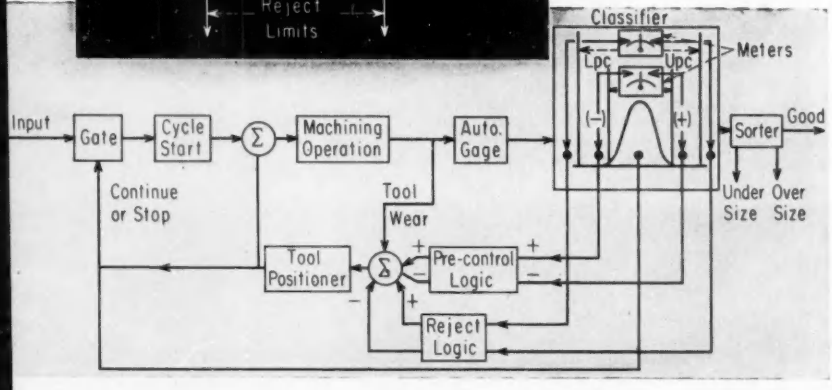


FIG. 12. *Block diagram of feedback gaging system.*

causing deflection of the meter pointer.

If the reactance of the gage head is higher than that of the compensator, the voltage C2 is negative and the voltage of C1 is positive, both with respect to point *B*. Again, current flows through the meter, but this time in the opposite direction, reversing the pointer deflection. The amount and direction of deflection of the meter is dependent, then, on the relative reactances of the gage head and the compensator. The low-capacity meter contacts are connected to the grid circuits of four thyratron tubes, which in turn operate relays that set up the stepper-switch memories or the reject logical circuits.

A basic characteristic of the circuitry described is that it is not fail-safe. Thus certain design precautions must be taken because the failure of a meter coil, a meter contact, a thyratron tube, or an associated relay could prevent a pulse from reaching the logical circuitry—tantamount to indicating a "perfect" piece. A self-checking circuit is therefore included in the form of four reference reactances. These are successively interrogated by a scanning switch once per work cycle and are set so as to simulate each gaging threshold. That is, one of each of these reactances is set just outside of a corresponding zone boundary (oversize—precontrol; undersize—precontrol; oversize—reject; undersize—reject) to test the meter coil, meter contact, associated thyratron, and corresponding relay. If any threshold condition fails to operate the circuit associated with it, the system is shut down and one of four indicator lights lit to show which circuit is affected. During this checking, the memory and reject circuits are disconnected.

Figure 12 shows the entire system in block-diagram form, with the various feedback loops indicated. The precontrol loop includes facilities for adjusting the precontrol limits, selecting the *n*-successive pieces, and choosing the magnitude of the tool correction increment. Thus, it provides all the elements needed to achieve the sensitivity, speed of response, and stability levels demanded by the particular application. The characteristics of the application that dictate what settings and values are chosen are the relation of the process capability to the allowed tolerance, the rate at which the process may be expected to shift, and the nature of the shift (one-directional or two-directional).

How does this control system compare in effectiveness with the several other possible ways of achieving automatic statistical regulation? The "best" control plan may be defined as that which produces the greatest product uniformity, or that which results in the least increase in the standard deviation beyond that of the basic process capability. Since any regulating system operates in response to error, there will always be some increase in the standard deviation as a result. This fact may be used as the measure of effectiveness; that is:

$$R.E. = \frac{\sigma_1}{\sigma_2}$$

where σ_1 = product sigma for best control plan
σ_2 = product sigma for plan under consideration
$R.E.$ = Relative Effectiveness

Tests for relative effectiveness of any actual or hypothetical control system can be made by analytical methods without building and testing the system itself. Remember that these are processes in which time-to-time or piece-to-piece variations are random except for some known and assignable cause for slow drift. For analyzing a continuous flow process, the designer can stimulate the process output by means of a random (or "white") noise generator. For analyzing a discrete-part process, he can use available tables of random numbers.

If a table of numbers is plotted against an equal-time-interval scale, a plot like that in Figure 10A is obtained (the band, of course, will be horizontal, having no trend). But obviously a trend can be imposed on such a plot of numbers, depending on the rate at which the characteristic in question is expected to drift out of limits, and this has actually been done in the figure. It is possible, thereby, to simulate the output of the process and even assume various rates of drift. Then by imposing on this unregulated output any desired type of monitoring and feedback system (incremental or proportionalized, Figure 10B), the effect of regulation on the resultant output can be determined. Further, the product sigma of the basic process capability can be compared to the product sigma of the regulated process to determine relative effectiveness. Obviously this can be done without actually constructing the system itself, and in most cases can be done with a fairly simple digital computer.

All of the several acceptable approaches indicated earlier can be designed to perform at a level of relative effectiveness on the order of 95 percent. The machine designer therefore is in general guided by considerations of cost, simplicity, and reliability, rather than by operating effectiveness.

a report on . . .
OPTIMIZING CONTROL of a CHEMICAL PROCESS

Results of research in optimizing control at Case Institute prove the feasibility of computing-control: a savings in time of 23 percent in processing batch reaction. Eckman and Lefkowitz, who guided the research, show that a batch process, whose kinetics are known only approximately, can be controlled so that:

- ***a product of specified composition is produced***
- ***the processing follows an optimum path described by the proper differential equations dependent on the nature of the process kinetics and on initial and final composition values***
- ***the optimum path yields a minimum processing time for the specified conditions of operation***

D. P. ECKMAN
I. LEFKOWITZ,
Case Institute of Technology

A primary objective of an industrial process is a uniform product of specified quality produced with maximum economy and efficiency. This objective can be attained under optimized operating conditions expressed by optimizing and control equations programmed into a computing-controller. These equations depend not only on the process, but also on performance criteria established by management. Costs of labor and raw materials, availability of materials, productivity, process limitations, and market conditions help determine these criteria.

The production of a specified product at minimum cost reflects optimum control. A cost equation, on which a minimization procedure yields the necessary relationships for minimum-cost manipulation of processing variables, includes the major cost factors of raw material, energy, labor, by-product recovery, off-standard production, overhead, etc. Thus, the overall processing cost can be written as a function of the processing variables:

$$C = f(V_1, V_2, \ldots V_n) \qquad (1)$$

where: C = overall processing cost
V_i = general processing variables

Continuous-process optimization

For continuous processes, minimum-cost (optimizing) equations may be derived by differentiating the cost-of-production equation with respect to each of the variables to be manipulated and setting the partial derivatives equal to zero. Thus, differentiating Equation 1 with respect to the process variables V_1, V_2, $V_4 \ldots V_{n-m}$ yields n-m equations of the form:

$$\left(\frac{\partial C}{\partial V_i}\right)_{V_j \neq n-m} = 0 \quad i, j = 1, 2, \ldots, n-m \qquad (2)$$

Application of these additional optimizing relationships then completely fixes the system, establishing the conditions for minimum-cost operation. Information describing the state of the process enters a computer, which determines the necessary optimization conditions and then transmits control signals back to the process.

Batch-process optimization

Material and energy costs in batch-process operation are generally relatively independent of processing conditions. The major controllable costs in the present application are labor, overhead, and apportioned plant investment. All of these increase with processing time, so that the time required per batch is the controlling cost item and the optimum processing path is the minimum time path.

The total processing time of a batch process is expressed as an integral of some function of the composition variables of the reaction mixture:

$$t_f = \int_0^{v_f} F(u', u, v)dv \qquad (3)$$

where: t_f = total processing time
v_f = product composition value
u, v = composition variables
$u' = du/dv$

To find the minimum t_f, apply the Euler-Lagrange relation to Equation 3:

$$\frac{\partial F}{\partial u} - \frac{d}{dv}\left(\frac{\partial F}{\partial u'}\right) = 0 \qquad (4)$$

where: $F = F(u', u, v)$ = the integrand of Equation 3. Equation 4 defines the optimum processing path for the functional relationship among the composition variables which satisfies a specified product composition in the shortest processing time. The process is guided along this path by a computing-controller that changes operating conditions (for instance, temperature and pressure) as kinetics dictate.

One way to guide the process is by repetitive computation of the optimum path, the computation proceeding at a much faster rate than the process itself. Initial conditions for each computation are determined from then-existing values of the process composition. As a result, the optimum path is always extrapolated from the present state of the process (not from the initial starting point) to the specified final state. Errors in the control function are not cumulative. In fact, there is a strong controlling action forcing the process to the specified composition despite any appreciable discrepancies in the computer equations describing the process.

THE HYDROGENATION PROCESS

A research project in optimizing control was carried out on the batch hydrogenation of cottonseed oil, a process that has widespread applications in the manufacture of oleomar-

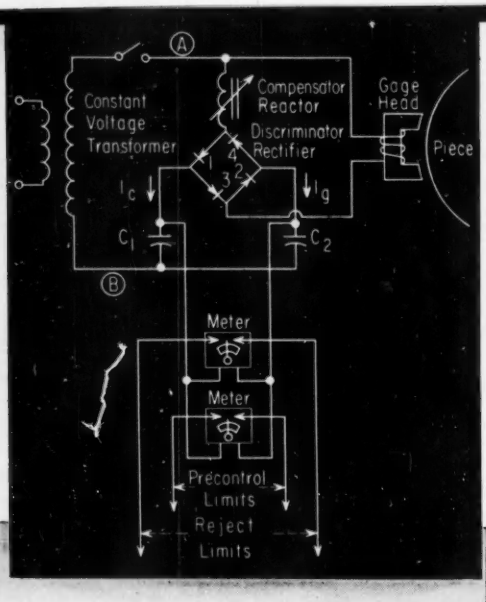
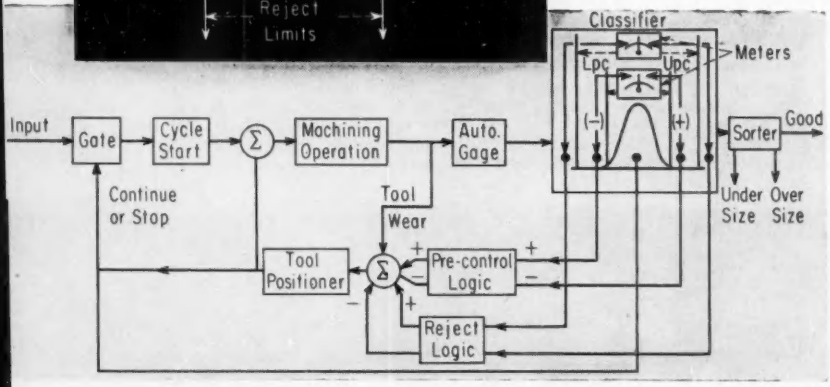


FIG. 11. Schematic diagram of logical circuitry.



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I. LEFKOWITZ,
Case Institute of Technology

A primary objective of an industrial process is a uniform product of specified quality produced with maximum economy and efficiency. This objective can be attained under optimized operating conditions expressed by optimizing and control equations programmed into a computing-controller. These equations depend not only on the process, but also on performance criteria established by management. Costs of labor and raw materials, availability of materials, productivity, process limitations, and market conditions help determine these criteria.

The production of a specified product at minimum cost reflects optimum control. A cost equation, on which a minimization procedure yields the necessary relationships for minimum-cost manipulation of processing variables, includes the major cost factors of raw material, energy, labor, by-product recovery, off-standard production, overhead, etc. Thus, the overall processing cost can be written as a function of the processing variables:

$$C = f(V_1, V_2, \ldots V_n) \qquad (1)$$

where: C = overall processing cost
V_i = general processing variables

Continuous-process optimization

For continuous processes, minimum-cost (optimizing) equations may be derived by differentiating the cost-of-production equation with respect to each of the variables to be manipulated and setting the partial derivatives equal to zero. Thus, differentiating Equation 1 with respect to the process variables V_1, V_2, V_i . . . V_{n-m} yields n-m equations of the form:

$$\left(\frac{\partial C}{\partial V_i}\right)_{V_j \neq_{n-m}} = 0 \quad i, j = 1, 2, \ldots, n-m \qquad (2)$$

Application of these additional optimizing relationships then completely fixes the system, establishing the conditions for minimum-cost operation. Information describing the state of the process enters a computer, which determines the necessary optimization conditions and then transmits control signals back to the process.

Batch-process optimization

Material and energy costs in batch-process operation are generally relatively independent of processing conditions. The major controllable costs in the present application are labor, overhead, and apportioned plant investment. All of these increase with processing time, so that the time required per batch is the controlling cost item and the optimum processing path is the minimum time path.

The total processing time of a batch process is expressed as an integral of some function of the composition variables of the reaction mixture:

$$t_f = \int_0^{v_f} F(u', u, v)dv \qquad (3)$$

where: t_f = total processing time
v_f = product composition value
u, v = composition variables
$u' = du/dv$

To find the minimum t_f, apply the Euler-Lagrange relation to Equation 3:

$$\frac{\partial F}{\partial u} - \frac{d}{dv}\left(\frac{\partial F}{\partial u'}\right) = 0 \qquad (4)$$

where: $F = F(u', u, v)$ = the integrand of Equation 3. Equation 4 defines the optimum processing path for the functional relationship among the composition variables which satisfies a specified product composition in the shortest processing time. The process is guided along this path by a computing-controller that changes operating conditions (for instance, temperature and pressure) as kinetics dictate.

One way to guide the process is by repetitive computation of the optimum path, the computation proceeding at a much faster rate than the process itself. Initial conditions for each computation are determined from then-existing values of the process composition. As a result, the optimum path is always extrapolated from the present state of the process (not from the initial starting point) to the specified final state. Errors in the control function are not cumulative. In fact, there is a strong controlling action forcing the process to the specified composition despite any appreciable discrepancies in the computer equations describing the process.

THE HYDROGENATION PROCESS

A research project in optimizing control was carried out on the batch hydrogenation of cottonseed oil, a process that has widespread applications in the manufacture of oleomar-

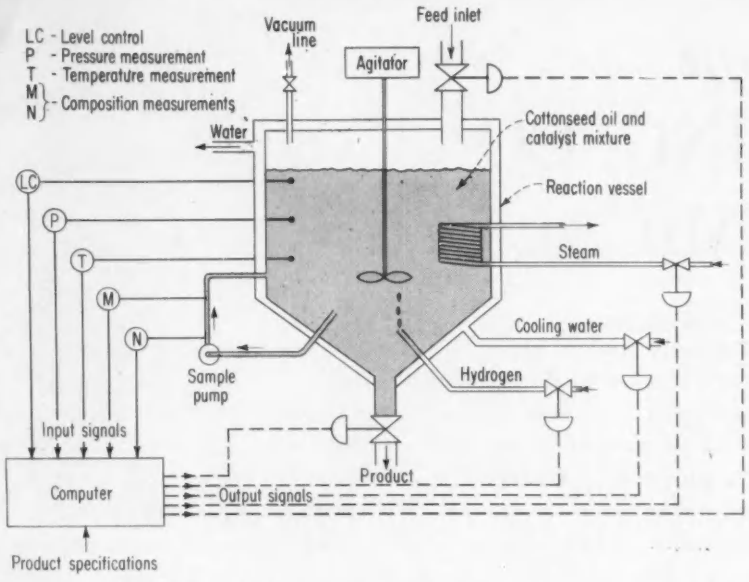


FIG. 1. The hydrogenation process in the autoclave reactor, guided by a computing-controller, turns out a specified product in minimum time.

garine, shortening, and other edible products. Under the influence of a nickel catalyst and at elevated temperature and pressure, hydrogen is added to fatty-acid glycerides of cottonseed oil. Hydrogenation affects product properties by raising the melting temperature of the oil to make it a solid at normal temperatures and by improving "keeping quality" (chemical stability), taste, and odor.

Cottonseed oil is a complex mixture of fatty-acid glycerides:

$$\begin{aligned} &R_1-O-CH_2 \\ &\quad\vert \\ &R_2-O-CH \\ &\quad\vert \\ &R_3-O-CH_2 \end{aligned}$$

where the R's represent fatty-acid radicals of linoleic, oleic, elaidic, and stearic acid. Since just the fatty-acid radicals in the molecule undergo hydrogenation, only the reactions of the fatty acids need be considered. In commercial processing, these take place in the indicated direction:

$$\text{Linolenic acid} + \text{hydrogen} \xrightarrow{\text{catalyst}} \text{oleic acid}$$

$$\text{Linoleic acid} + \text{hydrogen} \xrightarrow{\text{catalyst}} \text{elaidic acid}$$

$$\text{Oleic acid} + \text{hydrogen} \xrightarrow{\text{catalyst}} \text{stearic acid}$$

$$\text{Elaidic acid} + \text{hydrogen} \xrightarrow{\text{catalyst}} \text{stearic acid}$$

Product composition

Product properties are functions of product composition. Chemical stability improves with a decrease in linoleic concentration and an increase in stearic concentration. But since a large stearic concentration results in too high a melting point, the reaction can be carried along only to the time at which it yields a product with an intermediate composition consistent with the desired properties.

Product composition depends on:

- ▶ composition of raw material (cottonseed oil)—wide variations in composition cause variations in batch behavior and thus different operating conditions for specified final products. This limits the effective use of programmed-controlled process conditions.
- ▶ catalyst activity—the preparation of the nickel catalyst, its concentration, and its degree of poisoning affect reaction kinetics. Poisoning reduces catalyst activity as the reaction progresses.
- ▶ operating conditions during reaction—the most important operating conditions are temperature and pressure because these are most easily manipulated. Agitation also affects processing, but this is usually kept constant
- ▶ process duration—composition is greatly influenced by the time duration of the hydrogenation reaction.

Conventional operation

In conventional control of the hydrogenation process a mixture of cottonseed oil and catalyst is charged into the autoclave. Air and moisture are evacuated, the mixture is heated to start the reaction, and then hydrogen is introduced under pressure. Cooling water, flowing around the autoclave jacket during the exothermic reaction, prevents excessive temperature rise.

Temperature and pressure are kept at fixed values during the reaction period, typically 100 to 200 deg C and 50 to 300 psi. Process duration lasts from two to four or more hours. When measurements of refractive index and iodine value indicate specified product composition, the reaction is terminated, and the batch is dumped. After the catalyst is filtered out, the product is analyzed to see how close it comes to product specifications. Operating conditions are adjusted accordingly for the next batch. Blending of several batches yields specified product.

Computing-control

Figure 1 shows the hydrogenation process and a practical computing-control arrangement that:

- carries out the processing completely automatically
- produces a specified product
- minimizes production costs

The computer communicates directly with the process. Input signals supply information required for solving optimizing and control equations. They give autoclave level (thus initiating startup and shutdown for each batch); temperature and pressure (the process operating conditions); composition measurements (the state of the process); and product specifications (the set-point of the computing-controller).

Kinetic equations

Figure 2 represents the kinetics of the process. Chemical reactions involved:

$$X + H_2 \xrightarrow{k_1} Y \tag{5}$$

$$X + H_2 \xrightarrow{k_2} \bar{Y} \tag{6}$$

$$Y + H_2 \xrightarrow{k_3} Z \tag{7}$$

$$\bar{Y} + H_2 \xrightarrow{k_4} Z \tag{8}$$

$$Y \xrightarrow{k_5} \bar{Y} \tag{9}$$

$$\bar{Y} \xrightarrow{k_6} Y \tag{10}$$

where: X = linoleic acid concentration
Y = oleic acid concentration
$\bar{Y}$ = elaidic acid concentration
Z = stearic acid concentration
$k_1 \ldots k_6$ = kinetic reaction coefficients

According to the law of mass action, the rate of each of the above reactions is proportional to the product of the effective hydrogen concentration and the concentration of the respective fatty-acid reactant.

The reaction kinetics may be simulated by linear first-order differential equations of the form:

$$-dc/dt = kc \tag{11}$$

where: c = mol fraction of component C
k = kinetic coefficient

Equation 11 states that the rate of decrease of concentration of C due to its conversion in the reaction is directly proportional to its concentration, where the proportionality constant is the kinetic coefficient.

Applying Equation 11 to the reaction indicated by Equations 5 through 10 yields:

$$dx/dt = -(k_1 + k_2)x \quad (12)$$

$$dy/dt = k_1x - (k_3 + k_5)y + k_6\bar{y} \quad (13)$$

$$d\bar{y}/dt = k_3x - (k_4 + k_6)\bar{y} + k_5y \quad (14)$$

where: x, y, and $\bar{y}$ represent the mol fractions of components X, Y, and Y

The concentration of component Z need not be expressed explicitly because it is related to the concentrations of the other three components:

$$x + y + \bar{y} + z = 1 \quad (15)$$

Each kinetic coefficient is a function of the operating conditions:

$$k_i = f_i\,(P,\ T,\ K_C,\ K_A) \quad (16)$$

where: P = absolute pressure of hydrogen acting on the reaction mixture
T = absolute temperature
K_C = effective catalyst activity
K_A = degree of agitation

Normally, the catalyst and agitation effects change slowly and are taken as constants. Thermodynamic and experimental considerations indicate a dependency of the kinetic coefficients on pressure and temperature:

$$k_i = a_i P^{n_i} e^{-b_i/T} \quad (17)$$

where: a_i, n_i, and b_i are constants. Further, if the temperature is assumed constant (as is done here to reduce the analytical and experimental work and simplify computer setup) then Equation 17 reduces to:

$$k_i = A_i P^{n_i} \quad (18)$$

where: $A_i = a_i e^{-b_i/T}$

As the project proceeded, it seemed wise to keep the first stages of analysis and investigation of computing-control simple to encourage development of fruitful techniques and procedures. The derivation of an optimum path for the four-component six-reaction (4C-6R) system described by Equations 5 through 10 promised to be quite difficult and complex, particularly because of lack of information on relative parameter values, etc. Moreover, methods of measuring composition for the complete system were not immediately available.

Accordingly, the 4C-6R system was effectively reduced to a three-component four-reaction (3C-4R) system by using, in the pilot plant model, a starting material containing negligible linoleic acid: $x \sim 0$. This permitted the direct application of instrumental methods of composition measurement to the process. It also reduced the complexity of the optimizing and control equations to within the limitations of the computing facilities.

Note that the process simplification employed here does not limit the usefulness or significance of the techniques developed or the equations derived. Thus, the results obtained in the present study are generally applicable to a great many processes of the indicated type and configuration.

Optimizing and control equations

The kinetic equations for the 3C-4R are obtained from Equations 12-14. With x negligible:

$$\frac{dy}{dt} = -(k_3 + k_5)y + k_6\bar{y} \quad (19)$$

$$\frac{d\bar{y}}{dt} = -(k_4 + k_6)\bar{y} + k_5y \quad (20)$$

where the kinetic coefficients are expressed, from Equation 18, as functions of pressure by:

$$k_3 = A_3P^{n_3} \quad (21a)$$

$$k_4 = A_4P^{n_4} \quad (21b)$$

$$k_5 = A_5P^{n_5} \quad (21c)$$

$$k_6 = A_6P^{n_6} \quad (21d)$$

Now define new variables:

$$w = \bar{y}/y \quad (22a)$$

$$q = \ln(y_i/y) \quad (22b)$$

The variable q serves as the independent variable in the following derivations. It has an initial value of zero and steadily increases as the reaction proceeds, so that w and other process variables can be expressed as single-valued functions of q. This eliminates time as the independent variable and permits the derivation of equations that depend only on process composition and operating conditions.

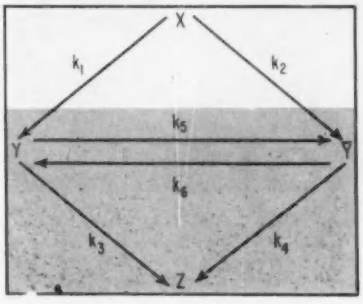
Appropriate mathematical manipulation and combination of Equations 19, 20, 22a, and 22b result in:

$$\frac{dw}{dq} = \frac{k_5 - (k_4 + k_6)w}{k_3 + k_5 - k_6w} \quad (23)$$

Equation 23 must satisfy the given initial and final composition values irrespective of the operating path and is termed the reaction control equation. This equation is an expression of composition path independent of the time co-ordinate. Its solution is a curve $w(q)$, which passes through the points $(w_i, 0)$ and (w_f, q_f) specified by the given initial conditions and desired final composition.

Theoretically, the process pressure can be varied in a great variety of ways and yield the desired final product composition according to Equation 23.

FIG. 2. This reaction diagram shows the hydrogenation process. The three-component four-reaction system (shaded) is the one actually controlled by the computer.



However, the performance criteria requires that the reaction, in addition to producing the specified product composition, should be completed in minimum time.

The duration of the reaction is:

$$t_f = \int_o^{q_f} F(q)\,dq \quad (24)$$

where

$$F(q) = (k_3 + k_5 - k_6w)^{-1} \quad (25)$$

Applying the Euler-LaGrange relationship (Equation 4) to Equation 25 subject to the constraint imposed by Equation 23 results in an equation describing the minimum time path for the reaction. The optimizing equation (to be shown later in simplified form) is solved in the computer simultaneously with Control Equation 23 to satisfy the performance criteria.

Fortunately, the control and optimizing equations can be simplified by using information gained during a prior study of the reaction kinetics of the process. This reduces the amount of computing equipment yet keeps results free of any significant error. The kinetic study showed that:

$$k_4/k_3 \simeq k_6/k_5 \quad (26a)$$

$$k_3/k_5 < 1 \quad (26b)$$

$$n_3 = n_4 \quad (26c)$$

$$n_5 = n_6 \quad (26d)$$

Adapting the simplifications, the equations (actually simulated in the computing-controller) are:

$$w' = w + 1 - \frac{g(1 + Cw)}{g + 1 - Bw} \quad (27)$$

$$g' = (1 + w - w')\left[\frac{g}{(m-1)\,(1 - Bw)} - \frac{1 - Bw}{m}\right] \quad (28)$$

$$t' = \frac{Ag^{1-m}}{g + 1 - Bw} \quad (29)$$

$$P = \left[\frac{g^m}{AA_3}\right]^{1/n_3} \quad (30)$$

where: $g = k_3/k_5 = (A_3/A_5)\,P^{n_3 - n_5}$
$A = A_3^{m-1}/A_5^m$
$B = k_6/k_5 = A_6/A_5$
$C = k_4/k_3 = A_4/A_3$
$m = n_3/(n_3 - n_5)$
t = process time
P = operating pressure
$w = \bar{y}/y$
$q = \ln(y_i/y)$
$w' = dw/dq$; $g' = dg/dq$; $t' = dt/dq$

Simultaneous solution of Equations 27 and 28 yields two curves: an optimum processing path $w(q)$ and an optimum operating path $g(q)$. If the $w(q)$ curve is made to pass through the specified initial and final product composition points, then both curves are determined and the solution is unique. The actual process is made to follow $w(q)$ by manipulating the pressure such that g satisfies the corresponding $g(q)$ function.

Equations 29 and 30 supply relationships for expressing the computing-control signal as a pressure func-

tion of time, which is convenient in view of the intermittent sampling of product composition. This signal directly adjusts the set-point of the process pressure controller to optimize control of the process reaction.

PLANT DESIGN

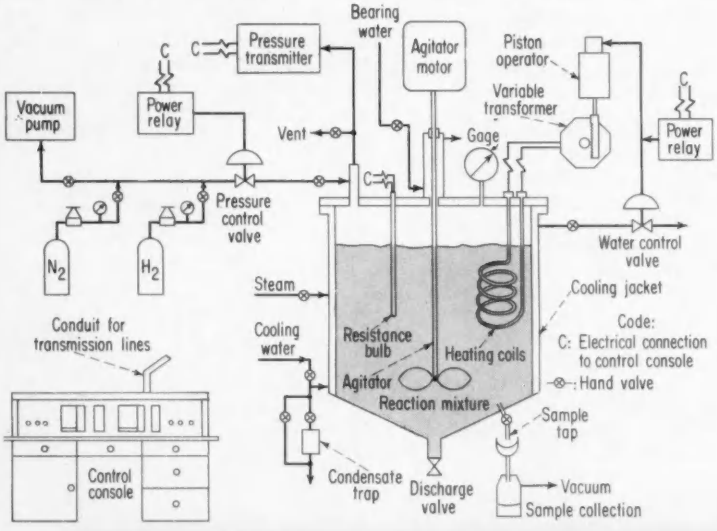
Figure 3 shows the batch reactor (autoclave), control console, instrumentation, and other equipment of the pilot plant on which the optimizing procedure was tried out. The autoclave is equipped with an agitator, a cooling jacket, and an electric heating coil. Openings permit adding hydrogen and pulling samples of the reaction mixture. The control console, located a short distance from the autoclave, contains standard electronic instrumentation, motor starting switches, and other operating elements.

Figure 4 gives a clear picture of one of two loops for controlling temperature and pressure. Both loops are identical except for the measuring transducers and actuators. A transducer measures the process variable and transmits its value to a continuously-recording strip-chart recorder-controller on the console. Control is effected by proportional, integral, and derivative actions. The set-point of the controller is adjusted either manually at the recorder-controller, or automatically by action of an output signal from the computing-controller. The recorder-controller's electrical output is converted, by a power relay, to a proportional air signal that actuates a valve to adjust a process variable. A manual station directly manipulates the process during abnormal operation.

Pressure is measured with a diaphragm-type transmitter having a range of zero to 600 psig. The controller output actuates a pneumatic valve in the hydrogen flow line.

Temperature is measured with a resistance temperature detector and a Wheatstone-bridge transmitter over a zero-to-200-deg-C range. The temperature controller output manipulates both the cooling water flow and the electric heater power through a split-range feature: the valve for water flow operates over a 3-to-10-psi air-pressure signal (open at 3 psi, closed at 10 psi), and the variable transformer supplying heater power is positioned by a piston operator over a 9-to-15-psi range (zero voltage at 9 psi, full line voltage at 15 psi). The instrumentation also includes safety controls.

FIG 3. Pilot plant for carrying out computing-control of a batch process.



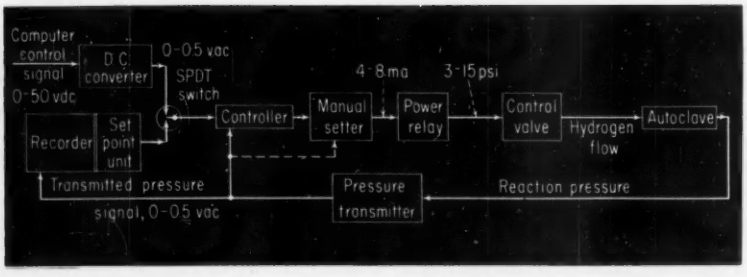


FIG. 4. The pressure-control loop: the set-point of the conventional pressure controller is determined by the control signal obtained from the computing-controller. A similar loop controls temperature (though in this study the temperature set-point was maintained constant throughout the run.)

Product composition analysis

The analytical procedure finally selected for the hydrogenation process, is based on the measurement of:

- refractive index at 75 deg C
- infrared absorption at 10.37 microns

Refractive index measures the total oleic and elaidic acid concentrations. Calibrating the refractometer against samples of known concentrations gave the curve in Figure 5, which relates the reading to a function Q:

$$Q = y + \tilde{y} \tag{31}$$

The infrared absorption at 10.37 microns is due mainly to elaidic acid, although oleic and stearic acids also contribute a measurable effect. The respective contributions were determined experimentally with known samples and resulted in the relationship:

$$(0.706\ y + 2.42\ \tilde{y} + 0.516\ z)\ W = \log_{10} 100/T \tag{32}$$

where: W = weight of sample in grams
T = percent transmission at 10.37 μ, corrected for zero reading.

Since the sum of the three concentrations must equal unity,

$$y + \tilde{y} + z = 1 \tag{33}$$

The three equations are solved simultaneously for $\tilde{y}$ in terms of the measured quantities Q, W, and T:

$$\tilde{y} = (0.585\ W^{-1}) \log_{10} 100/T - 0.111Q - 0.302 \tag{34}$$

Knowing the value of $\tilde{y}$, the value of y can be found:

$$y = Q - \tilde{y} \tag{35}$$

After a small sample is withdrawn and weighed out, the infrared transmission is determined with and without the sample in the refractometer test cell. Difference in the two readings supplies the value of T in Equation 34. A refractometer reading is taken after the sample has been cooled to precisely 75 deg C. The observed reading is referred to the calibration curve from which the value of Q is read. Equations 34 and 35 are solved simultaneously to yield the composition values.

COMPUTER PROGRAMMING

The equations that are to be set up on the computer must be transformed to the two computer variables, voltage and time. Thus, process variables w, g, and t are related to computer voltages W, G, and T, and the independent variable q is related to the comput-

ing time τ by the following transformation equations:

$$W = 40\ w \text{ (volts)} \quad (36a)$$
$$G = 200\ g \text{ (volts)} \quad (36b)$$
$$\tau = 80\ q \text{ (milliseconds)} \quad (36c)$$
$$T = 0.25\ t \text{ (volts)} \quad (36d)$$
$$Y = 40/y \text{ (volts)} \quad (36e)$$

With these transformation equations and parameter values obtained during a prior investigation of reactor kinetics, the computer equations can be derived from Equations 27-30:

$$80\ W' = W + 40 - \frac{G(40+0.67)}{G+200-3.0W} \quad (37)$$

$$80\ G' = (40+W+80\ W')\left[\frac{4.0G}{66.7-W} - 0.053(66.7-W)\right] \quad (38)$$

$$80\ T' = \frac{15{,}000\ G^{-0.42}}{G+200-3.0\ W} \quad (39)$$

$$P = 14G^{1.03} \quad (40)$$

where: W, G, and T = analogs of w, g, and t, in volts
W', G', and T' = derivatives with respect to τ
P = operating pressure, psia

Control of the batch hydrogenation process represents a combination of manual and automatic operations. Except for statistical treatment of input data, to be described subsequently, the manual control operations are readily mechanized with presently existing equipment to fully automatic operation (though this was limited here by lack of time and funds). The computing facilities, batch reactor, and analysis instruments are located in separate laboratories as shown schematically in Figure 6. An intercom system rapidly transmits analysis and control data between laboratories.

The operating procedure is:

1. The process composition is determined periodically by analyzing samples of the reaction mixtures taken at 5-min intervals, t_0, t_1, t_2, etc. Note that this is a realistic operation in that analysis instrumentation for a great many processes will not be (at least in the initial stages) automatic, continuous-acting, and lag-free.

2. Composition values, y and $\bar{y}$, are plotted against time. Smooth curves representing the functions $y(t)$ and $\bar{y}(t)$ are fitted to these plotted points. The general shape of the curves are described by the kinetic equations for the reactions, Equations 19 and 20.

3. The curves are extrapolated (over the composition measurement time delay) to the time t_i corresponding to the next sample period. The composition values $y(t_i)$ and $\bar{y}(t_i)$, taken off the curves, are transmitted as new w_i and q_f values.

4. The computer solves the optimizing and control equations (Equations 37 and 38 to determine the minimum time path from composition $[y(t_i), \bar{y}(t_i)]$ to the specified final composition $[y_f, \bar{y}_f]$. The resulting G (τ) function is sampled to pick off values G_0, G_1, G_2, . . . corresponding to successive sampling periods. These are converted to pressure values P_0, P_1, P_2, . . . by application of Equation 40. Equation 40 is plotted on log-log paper. Values of P are read off (manually) for computed G values corresponding to uniform increments of time. These pressure commands are then transmitted to the reactor through the intercom system. The sampling is obtained by means of sampling pulses whose width is proportional to process time as determined by Equation 39.

5. The reactor pressure is manipulated according to the $P(t)$ values defined for the interval immediately following t_i. Note that each new sample period supplies the computer with new conditions from which another set of $P(t)$ values is determined. This supersedes the previous set and provides the pressure control signals for the next immediate interval.

The computer circuitry for Equations 37, 38, and 39 is shown in Figure 7. The programming is relatively straightforward except for the generation of the function $G^{-0.42}$, designated in the upper left by the block S*. $G^{-0.42}$ is generated by using a Philbrick squaring component, with its exponent modified to 2.38, in the feedback circuit of an operational amplifier.

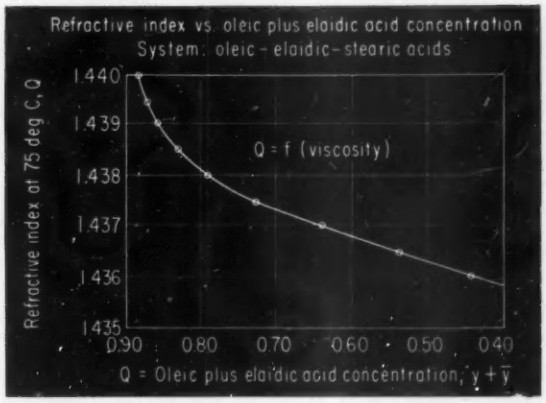


FIG. 5. Refractive index vs. oleic plus elaidic acid concentration. This calibration curve was used, instead of looking for explicit relationship.

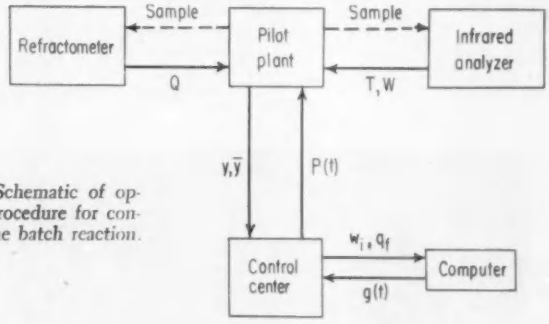


FIG. 6. Schematic of operating procedure for control of the batch reaction.

Computing interval

An important part of the computer is the definition of the computing interval, which starts at $\tau = 0$ and ends at τ_f. According to Equation 36c (considering the initial value of q to be zero):

$$\tau_f = 80\ q_f$$

Replacing q_f by its equivalent in terms of Y_i and Y_f (Equations 22b and 36e) and solving for Y_i:

$$Y_i = Y_f e^{-0.0125\tau_f} \quad (41)$$

But this may be obtained from the solution to the first-order equation

$$\frac{dY}{d\tau} + 0.0125\ Y = Y_f \quad (42)$$

for the conditions $Y = 0$, $\tau = 0$; and $Y = Y_i$, $\tau = \tau_f$. Accordingly, the computing interval is established as follows: A step input of Y_f volts is applied (at $\tau = 0$) to the computer circuitry solving Equation 42 under zero initial conditions. When the voltage Y reaches the value Y_i, a pulse P_o is generated which terminates the computation and identifies the end of the computing interval τ_f.

The circuit for generating the computing interval is shown in Figure 8; the resulting pulses are fed to

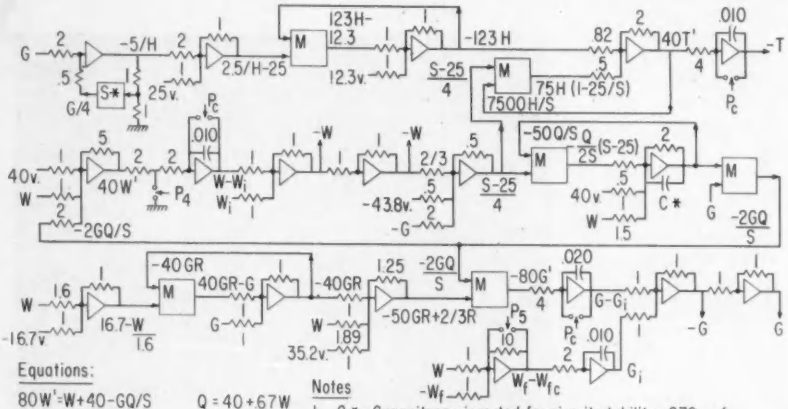


FIG. 7. Computer circuit representing the optimizing and control equations obtained from the kinetics of the reaction.

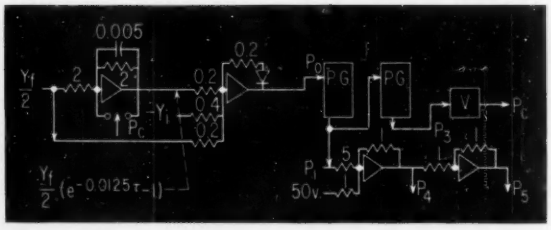


FIG. 8. This circuit generates the pulses that establish the computing interval. During interval the equations in Figure 7 are solved much faster than the process proceeds.

appropriate points of the computer circuitry, Figure 7, to solve the control and optimizing equations. The computer operates repetitively, generating a solution to the differential equations about 20 times a second. Electrical pulses, produced by pulse generators PG triggered by the computer, introduce initial and final conditions.

Figure 9 helps to explain computer operations. The computing interval starts (at $\tau = 0$) as soon as the clamping pulse P_c goes negative. This releases the integrators from their zero initial conditions and allows the computation to proceed according to the control and optimizing equations set up on the computer. The computing interval ends (τ_f) the instant that Equation 41 is satisfied. This is the point at which the voltage $Y_i - Y_f e^{-0.125\tau_f}$ passes through zero (see top curve of Figure 9). High-gain amplification and clipping of this voltage produces triggering pulse P_s. This sets off gating pulses P_1 and P_2, which establish the error sensing interval, to be described below. P_2 pulses are of a fixed short duration. Their trailing edge triggers pulse P_3 which generates the clamping pulse P_c, establishing the clamping interval. The clamping (P_c positive) forces the integrator output voltages to zero. When P_c goes negative again, the integrators are released once more and the cycle repeats.

Initial conditions

Initial conditions are applied directly by adding the appropriate voltage to the integrator output. That is, if the input to the integrator is $dW/d\tau$, then the output, neglecting the change of sign and the integrator constant, is $W - W_i$. Adding the initial value W_i then produces the desired variable W. Note that the integrator output is zero at the start of the computing interval because of clamping. Consequently:

$$W - W_i = 0 \text{ at } \tau = 0$$

which is consistent with the definition of W_i.

Boundary conditions

The technique described here was developed in connection with the present study and proved to be very effective despite its simplicity. However, it is adaptable only to high-speed computers operating repetitively.

The boundary condition is satisfied by manipulating G_i (the initial condition for Equation 38) until

$$W - W_f = 0 \text{ at } \tau = \tau_f$$

This is accomplished automatically by using the differences $W - W_f$ as the error signal to apply a correction to the G_i value of the previous computation.

At the instant τ_f the P_2 pulse grounds the input to the integrator generating W to fix the error signal during the error-sensing interval. Simultaneously, the P_3 pulse applies the error signal to the input of another integrator whose output (which is never clamped) is designated G_i. Integration of this error over the error-sensing interval produces a change in G_i proportional to the error and in the direction to reduce error to zero, as shown on the W and G_i plots in Figure 9. The G_i voltage is maintained constant outside of the error-sensing interval by action of P_3, which grounds the input to the G_i integrator.

The G_i value adjusts itself over the course of several computing cycles until the error signal is zero. The computer equations then satisfy the given conditions and G_i remains constant. When the conditions change, the operations outlined above repeat until a new balance is achieved. Because of the high repetition rate, this new equilibrium is reached within a fraction of a second and the computer thus responds almost instantaneously to variations in Y_i and W_i that reflect the course of the reaction.

The computer determines the optimum path from the present state of the process to the desired final state. Consequently, the initial value G_i represents the required operating condition for the process coincident with the start of the computing period. Since the computation is repeated many times faster than the rate at which the process changes, and since each computation is based on the existing state of the process, the G_i voltage traces, in stepwise fashion, the G (τ) curve corresponding to the optimum path. Therefore, it is possible to use this voltage directly to manipulate the pressure.

The control action of a typical reaction is shown in Figure 10. The steps are greatly exaggerated to emphasize the self-regulating attributes of the procedure. The abscissae t_1, t_2, t_3, . . . represent the start of the successive computing cycles (relative to the time measured from startup), while the ordinates W_{i1}, W_{i2}, W_{i3}, . . . represent the corresponding composition values transmitted to the computer. The latter serve as the

initial conditions for the respective computations. In like manner G_{i_2}, G_{i_3}, . . . satisfy the boundary conditions W_f for the successive cycles.

The path of the computer solution indicated by the dot-dash lines on Figure 10, and the one actually followed by the process is indicated by solid lines. Ideally, the dot-dash and solid curves should coincide. However, errors and approximations in equations, computer circuitry, and composition measurement introduce differences between the two. The dashed lines in the figure are the continuation of the solid lines and represent the composition path which would be followed if the same operating (G) paths were maintained. Since each successive computation is based on the new initial conditions (the present state of the process) the end-point draws closer as the reaction proceeds and the discrepancy in final composition becomes smaller.

RESULTS

A comparison of the results of an optimized run with the results of a conventional run dramatizes the benefits of computing-control. In conventional control of the batch reaction, hydrogen pressure is maintained constant during the reaction, which proceeds until the approximate range of the specified product composition is reached. In optimizing control, hydrogen pressure varies under the influence of the signals generated by the computing-controller, and the reaction is forced to specified composition in minimum time.

A constant-rate path run is obtained by setting G' (see Equation 38) to zero; i.e., the computer determines that constant value of G that satisfies the given initial and final composition values. The corresponding pressure is found from Equation 40. Figure 11 contains the plot of the composition variables y and $\bar{y}$ vs. time for the constant-rate path run. It also shows the control pressure called for by the computer at various stage of processing. Note that this is computing-control to a specified product without optimization.

Theoretically, the pressure should be constant throughout the constant-rate path run. The observed variations in control pressure are attributable to errors in analysis, errors in parameter values set up on the computer, effects of neglected side reactions and idealization of reaction kinetics, and the time delay between taking measurements and insertion of new data into the computer. Control action, the action of the computing-controller in manipulating the process pressure, compensates for these errors. The effectiveness of control action

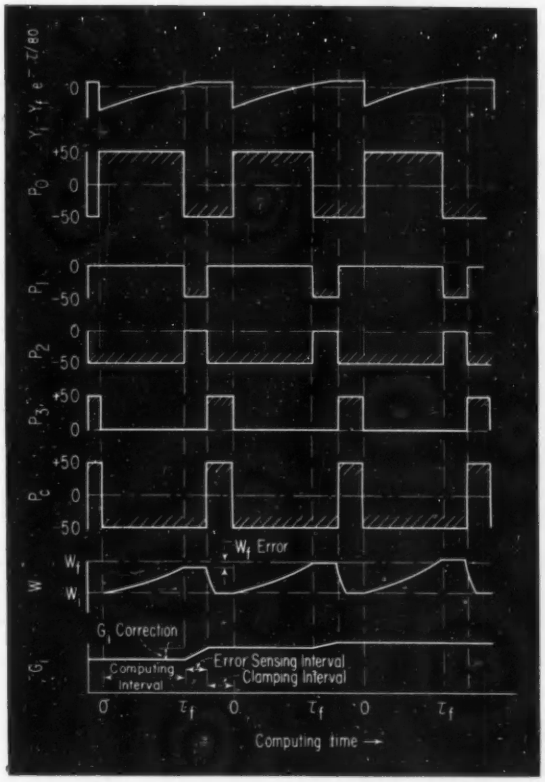


FIG. 9. Pulse-phase relationship during repetitive solution on the computer of typical optimizing and control equations. In a fraction of a second, as seen on the bottom curve, the computer rapidly reduces the error of the G signal, which in turn determines the operating pressure for the next interval.

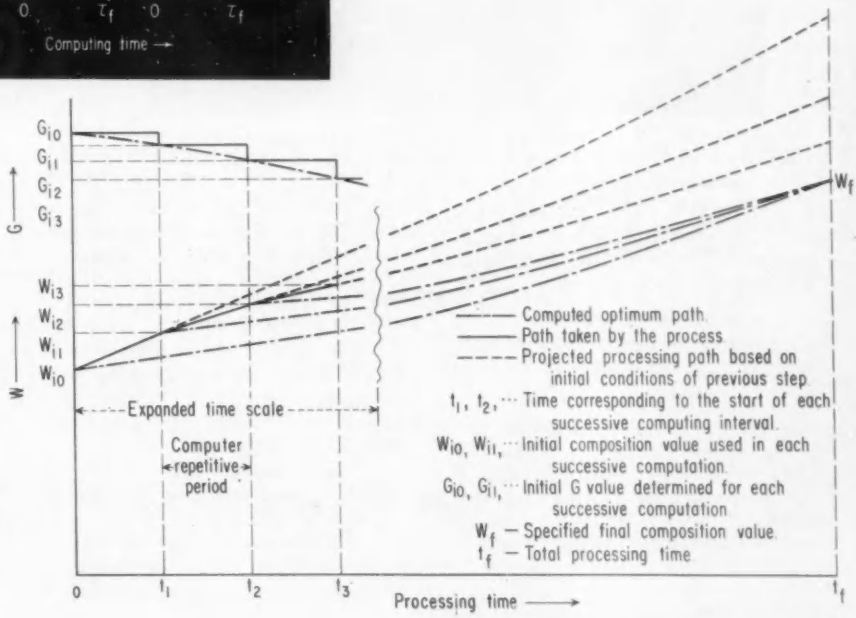

Expanded time scale
Computer repetitive period
Computed optimum path
Path taken by the process
Projected processing path based on initial conditions of previous step
$t_1, t_2, \cdots$ Time corresponding to the start of each successive computing interval
$W_{i0}, W_{i1}, \cdots$ Initial composition value used in each successive computation
$G_{i0}, G_{i1}, \cdots$ Initial G value determined for each successive computation
W_f — Specified final composition value
t_f — Total processing time
Processing time

FIG. 10. Step-by-step, the process converges to its specified final composition under the influence of the computing-controller.

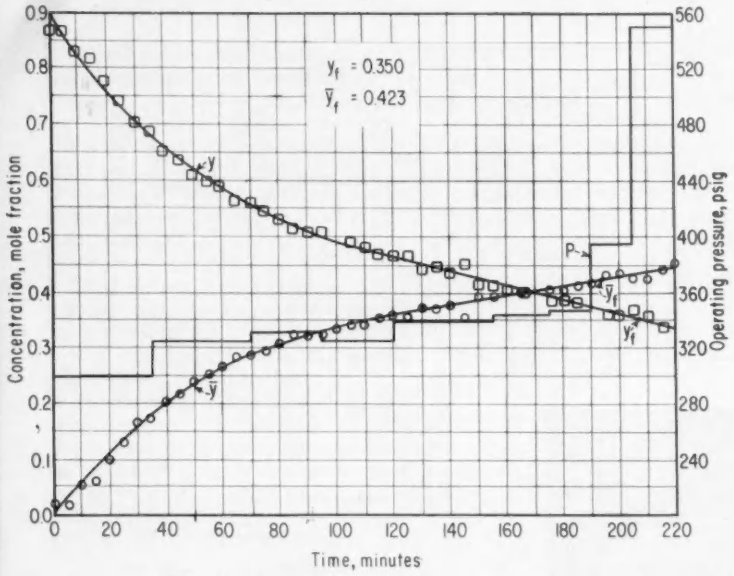


FIG. 11. Composition and pressure curves for computing-control constant-rate path run. Time to specified composition is 208 min.

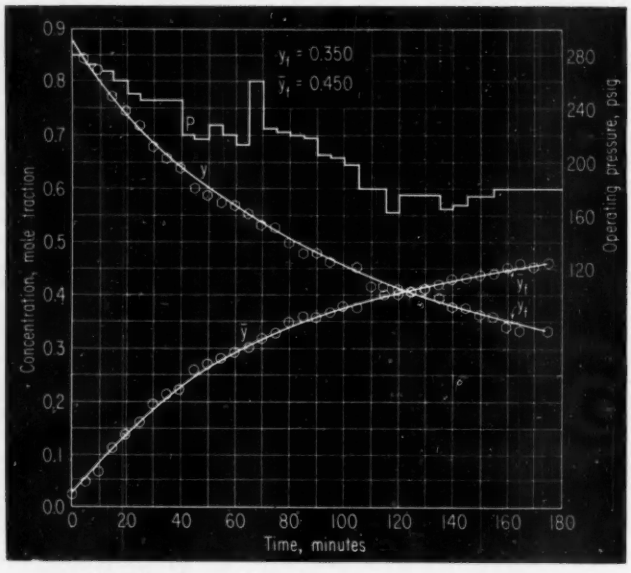


FIG. 12. Composition and pressure curves for computing-control optimum path run. Time to specified composition is 160 min.

is indicated by the closeness with which the specified final y and $\bar{y}$ composition values occur simultaneously. The specified end-point was:

$$\bar{y}_f = 0.423;\ y_f = 0.350$$

The actual end-point taken from the smoothed curve in Figure 11 was:

$$\bar{y} = 0.435 \text{ when } y = y_f = 0.350$$

But though the computer forced the constant-rate path run to a satisfactory final composition, it took 208 min.

In the optimizing path run the process was manipulated in accordance with the optimizing and control equations programmed into the computer. Thus, the computing-controller calls for a time variation in the operating pressure—such as to bring the reaction to its specified final composition value in minimum time. The results of such a run, Figure 12, show that:

$$\bar{y} = 0.450 \text{ when } y = y_f = 0.350$$

which is in very good agreement (considering the experimental accuracy of composition measurement) with the specified end-point:

$$y_f = 0.446;\ y_f = 0.350$$

The optimum path run took only 160 min, a significant decrease in time from the 208 min for the constant-rate path run. Thus, optimizing control resulted in a 23 percent reduction in batch time.

FURTHER RESEARCH

Case Institute's work has been in the nature of an exploratory investigation into the feasibility of computing-control of industrial processes. Though the two years of study have produced gratifying and encouraging results, there are many important aspects yet to be thoroughly examined. Among these aspects are:

1. Solving the optimizing control equations of the hydrogenation process on a general-purpose digital computer. This will permit more accurate performance, handling of complete equations without simplifying assumptions, automatic curve fitting and data smoothing, and time-sharing of the computing-controller.

2. Studying self-checking and feedback in the computing-control loop to improve methods of handling process information and determining and applying parameter corrections. Self-checking adjusts the parameters of the computer equations such that the computer accurately describes process behavior in the vicinity of the operating point.

3. Optimizing the control of a continuous process by studying the methods for compensating for dynamic lags in measurement and control, deriving optimizing equations which include the process dynamics, and deriving techniques for computing-control of a continuous process.

4. Studying the economic aspects of optimizing control. This will include the development of cost-of-production equations for a given process in terms of manipulated variables and an evaluation of contributions of the computing-control system to the overall economic picture.

5. Eventually, after the principles and techniques of process optimization have been fully developed, putting them to a practical test on an on-stream industrial process.

ACKNOWLEDGEMENTS

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- Westinghouse Electric Corp.

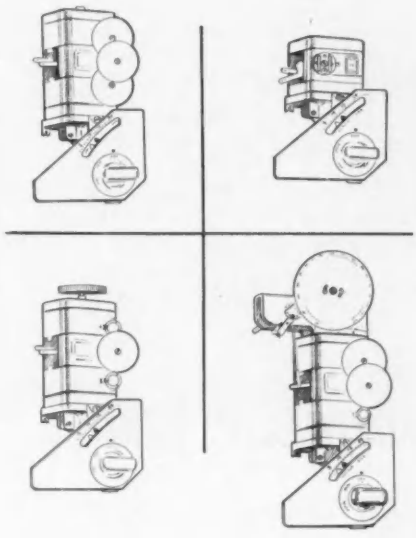
The research was under the direction of:

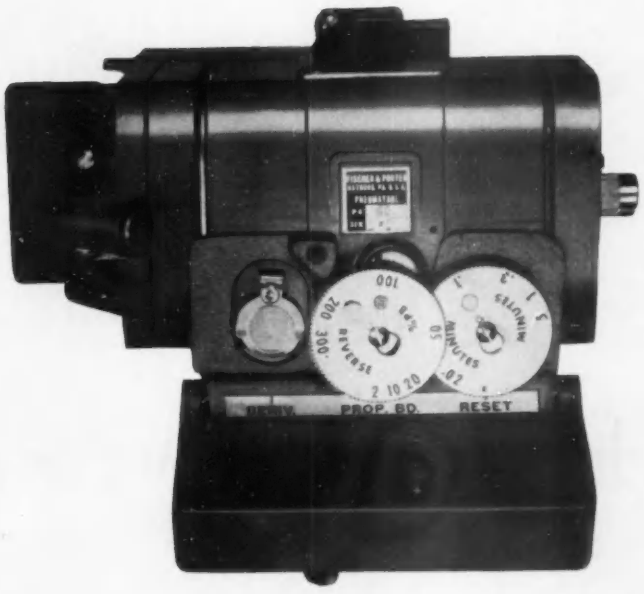
- D. P. Eckman—Professor of Instrumentation Engineering
- T. J. Walsh—Professor of Chemical Engineering
- F. E. Brammer—Associate Professor of Electrical Engineering

Members of the project team: P. G. Lafyatis, W. H. Ko, R. E. Knapp, B. Plujko, R. W. Heckleman, and A. S. Powell

The report was prepared and edited by:

- I. Lefkowitz—Research Associate in Mechanical Engineering





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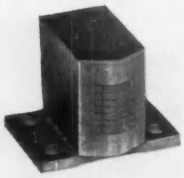

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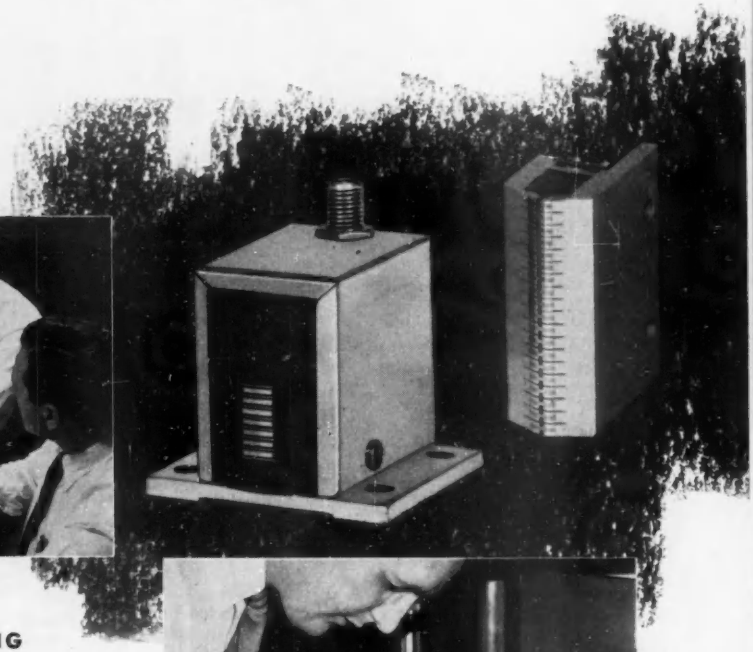

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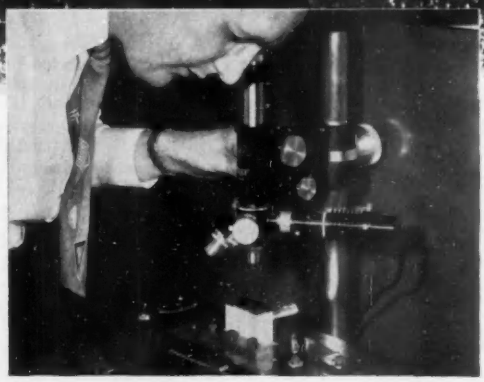

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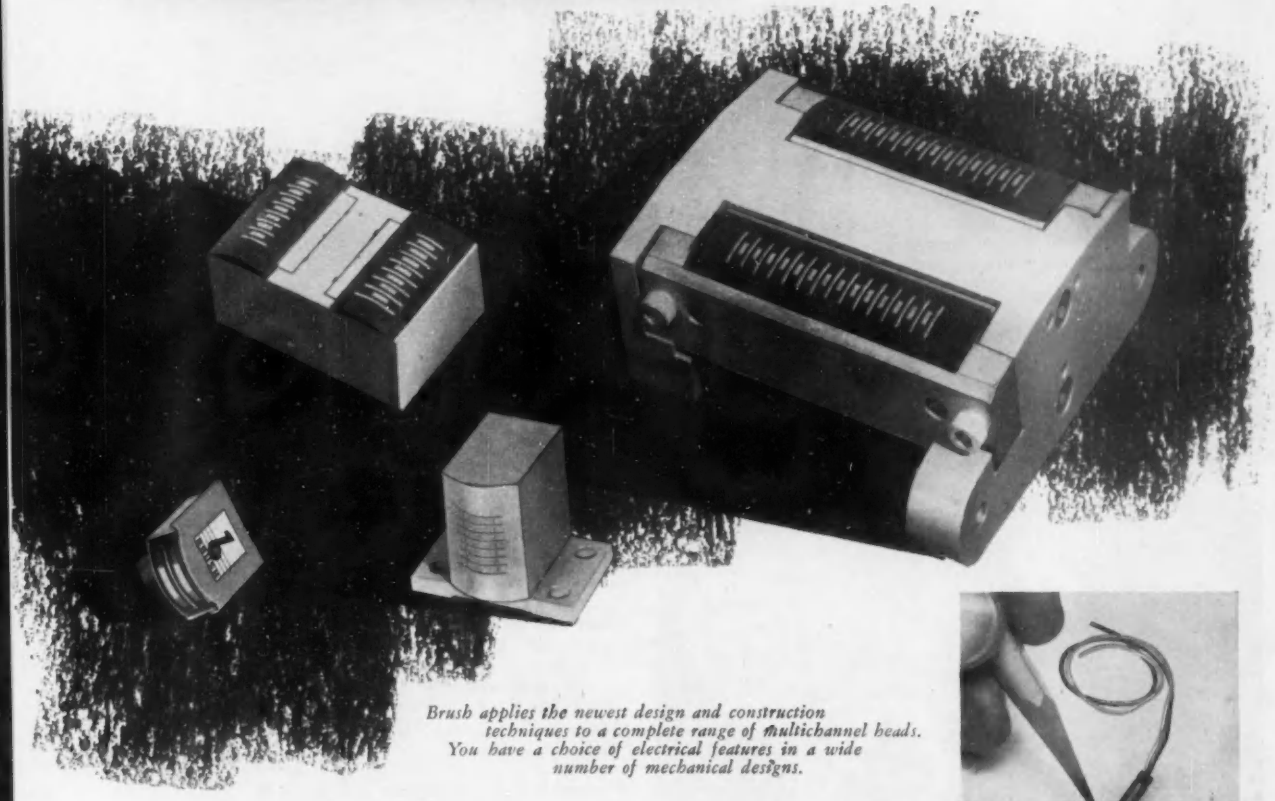

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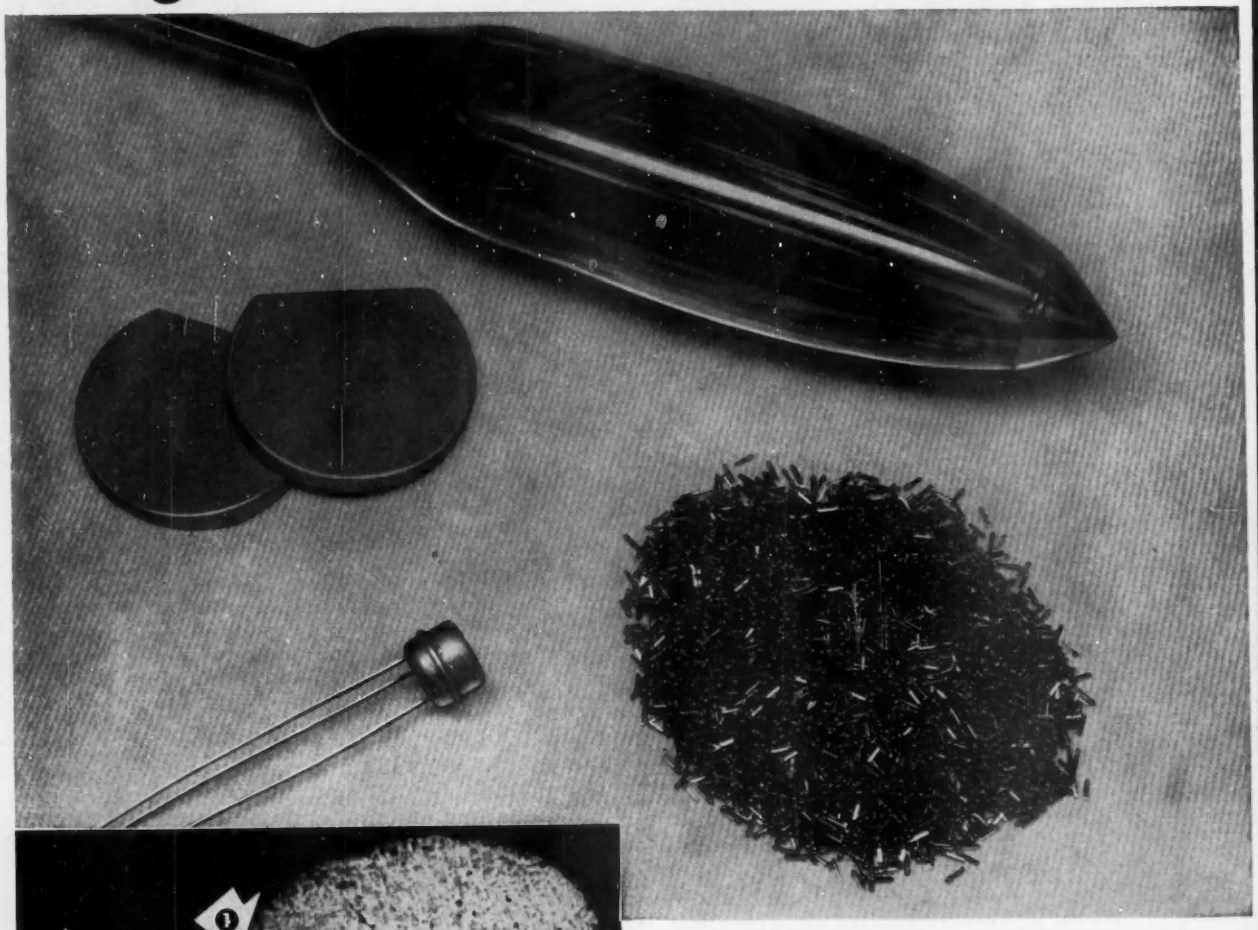
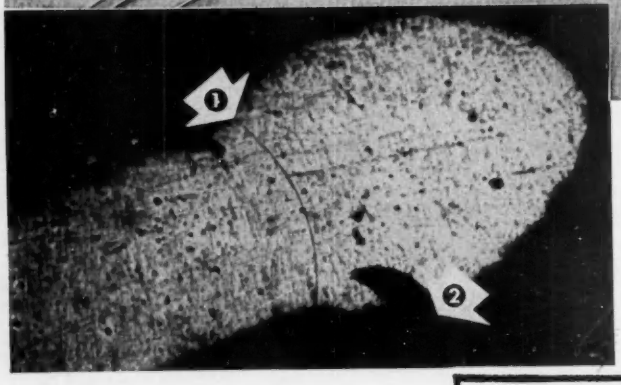
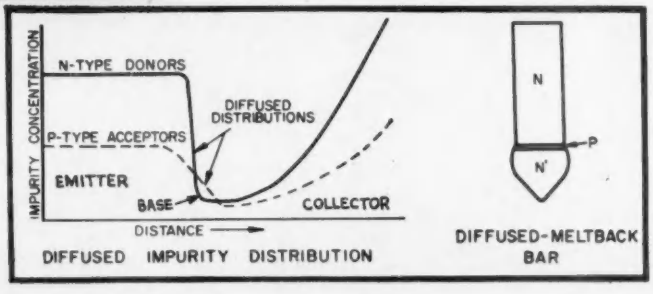




Before going through the diffused-meltback operation, a crystal of silicon is sawed into wafer-form: wafers are then diced to produce 4000 to 5000 individual silicon bars. Photomicrograph at left shows size-comparison of a silicon NPN bar, or pellet, with human hair (Arrow 2). "Tear drop" at end of bar is formed during meltback process. Micro-thin base, or "P", region (Arrow 1) is created through G-E diffusion technique. Base regions of 2-micron size are made with relative ease.

Curves illustrating impurity distribution after diffusion. P-type impurities in the high concentration side of the meltback junction diffuse, within solid semiconductor, into "plateau" region of low impurity concentration. High resistivity "plateau" contributes to elimination of punch-thru effects.



to put the most into transistors

High degree of uniformity and control in junction formation. General Electric's diffused-meltback process was developed by Dr. I. A. Lesk of the G-E Advanced Semiconductor Laboratory. The development came about as the result of Dr. Lesk's efforts to create a transistor manufacturing process that would yield high-quality results at reasonable cost.

Not only does the G-E diffused-meltback process result in a maximum number of transistors from a single crystal (4000 to 5000 NPN transistors), *but it offers an extremely high degree of uniformity and control in transistor junction formation.*

Opens the door to high frequency performance. Diffusion of a melted-back silicon bar, or pellet, is the final step in the diffused-meltback process. It's the stage in which the micro-thin base, or "P" region is formed, establishing the final NPN transistor structure. Because the actual diffusion is accomplished over a high temperature heating cycle lasting several hours, the need for split-second accuracy is eliminated. The result is a high degree of process control.

By proper choice of the initial impurity concentrations and the time and temperature of the diffusion cycle, heavily-doped base regions as thin as 2 microns are easily obtained. *These micro-thin, uniform base regions are the "open-sesame" to extremely reliable high frequency transistor performance.*

Ordering Data—G-E Silicon NPN Transistors

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ask for:		Beta
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High current gain. Silicon NPN transistors feature inherent high current gains and high frequency cut-offs. The diffused meltback process permits mass production, since it combines the principles of impurity segregation and solid-state diffusion.

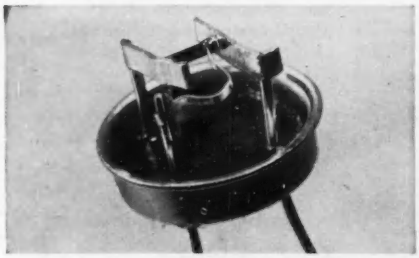
G-E silicon NPN transistors are nominally rated for 25 megacycles, but with useful gain to 50 megacycles—the highest frequencies offered by any mass-produced silicon NPN triode on the market today. All production units are aged at extremely high temperatures for over 150 hours. This is to provide maximum stability of I_{co} and current gain (beta).

The header assemblies of G-E silicon NPN transistors are constructed of high-purity materials. A gold-silicon alloy is used for end connections: the base lead is pure aluminum. There are no solders or fluxes, eliminating any danger of transistor "sleeping sickness" caused by corrosion at soldered junction points.

Outstanding For Switching Applications and Linear Amplifier Use. The gold-alloy mountings, with a melting temperature of over 350°C represent the lowest melting point of the entire transistor assembly structure. The G-E Series 4JD4A silicon transistors provide reliable operation to 150°C, with storage temperatures to 200°C.

With well-controlled high frequency characteristics and a low saturation resistance of 40 ohms, G-E silicon NPN transistors are "naturals" for switching applications and linear amplifier use.

Would you like complete specification information? Please contact your nearest G-E Semiconductor Products district office, or write to General Electric Company, Semiconductor Products, Section S1697, Electronics Park, Syracuse, N. Y.



View of uncapped G-E silicon NPN diffused-meltback transistor, showing mounted silicon bar with aluminum base lead connected. Bar ends attached using a gold-alloy mounting technique. No solders or fluxes are used.

Diffusion furnace. Operator places quartz vials, with large quantity of silicon bars, in furnace. Diffusion occurs through high-temperature heating cycle lasting several hours.

An aging oven in which G-E silicon NPN transistors are aged at extremely high temperatures for over 150 hours. Provides maximum stability of I_{co} and current gain (beta).

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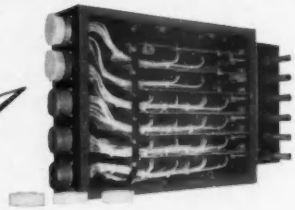

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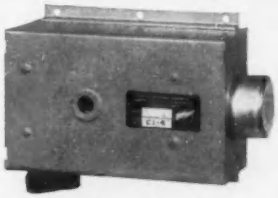
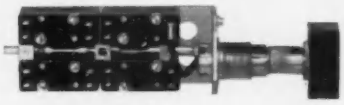


powering and de-powering
projectiles is dependably accomplished with this compact, hermetically-sealed assembly. Automatically actuated, it can be manually overriden. Design utilizes E-S rotary hermetic seal.



fire control switch
assures proper sequence during emergency fire conditions. Eliminates pilot error by controlling all functions when single handle is pulled.

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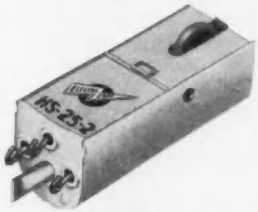

rocket safety switch
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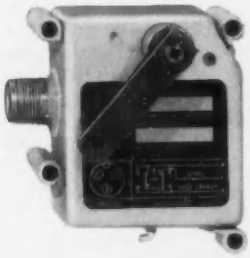

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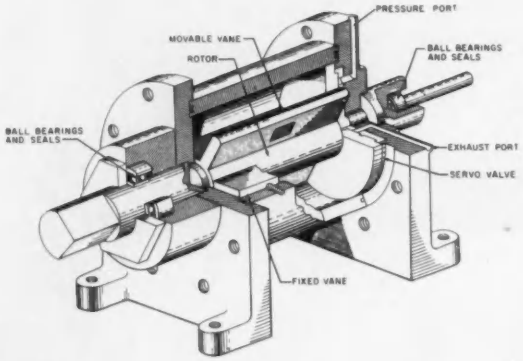
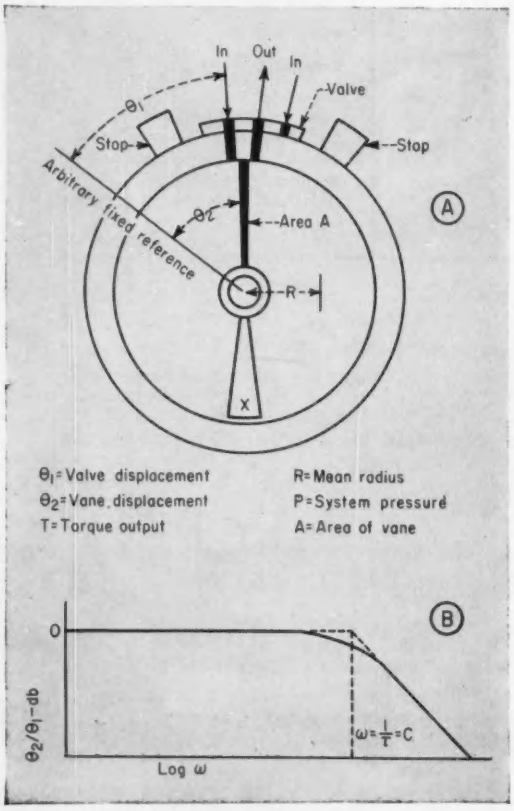
Accessories & Materials





θ_1 = Valve displacement
θ_2 = Vane displacement
T = Torque output
R = Mean radius
P = System pressure
A = Area of vane

ROTARY ACTUATOR has integral servo valve

The ICP Integral Servo Valve Rotary Actuator, shown here in a cutaway sketch, can be considered a closed-loop servo. Its output and input circuits are hydraulically interrelated so that the output shaft will always take the position commanded by the input shaft. The device is in reality a high-power, high-torque amplifier, because a small input torque (in the order of inch-ounces) can control an output torque of thousands of foot-pounds, depending, of course, on the size of the particular model. The input shaft may be driven mechanically by means of cables, rods, or some other device. Electrically, a servo motor, synchro, or rotary solenoid can do the job.

The unit eliminates the need for all but two connections, one each for pressure and exhaust. Models are available with one set of vanes which move through an arc of 270 deg. A second set of vanes gives twice as much torque, but the arc is cut down to 95 deg. Six sizes are available, with diameters ranging from 4 to 12 in. Output torques vary from 7,500 to 360,000 in.-lb. at 1,000-psi hydraulic pressure. Operating time for extreme travel is approximately 3 sec per stroke at flows of from 8 to 60 gpm. Optimum torque amplification is 1,500. The time constant of the unit is in the vicinity of 0.05 sec, with a break frequency of 20 rad per sec.

For a brief static servo system analysis, consider sketches A and B. Sketch A simplifies the valve representation by assuming that the outer cylinder and the movable vane rotate. X is the stationary or fixed vane. Assuming the valve to be rotated at constant velocity, the steady state torque at the output shaft equals $P \times A \times R$ (see the nomenclature).

After the system is at rest, assume that the valve is moved through a finite angle. The valve opening is then equal to the difference between θ_1 and θ_2. Next, assume a constant, C, equal to vane displacement per second divided by unit valve displacement. This constant depends upon valve design, flow, and pressure. If the effect of the load is negligible, then:

$$C(\theta_1 - \theta_2) = s\,\theta_2, \quad \text{or} \quad \frac{\theta_2}{\theta_1} = \frac{1}{1 + (s/C)}$$

where s is the Laplace operator. The first equation says that the velocity of the output vane is proportional to the valve opening for a fixed set of conditions. In the second equation, $1/C$ equals τ, the time constant of the system. Oscillating the valve over an incremental angle will cause the output shaft to oscillate at the same frequency. Sketch B shows the ratio θ_2/θ_1 in decibels plotted against log frequency in radians. This is a single time constant system and cannot be unstable if the dynamics of the load can be neglected.—Industrial Control Products, Inc., Caldwell, N. J.

Circle No. 1 on reply card

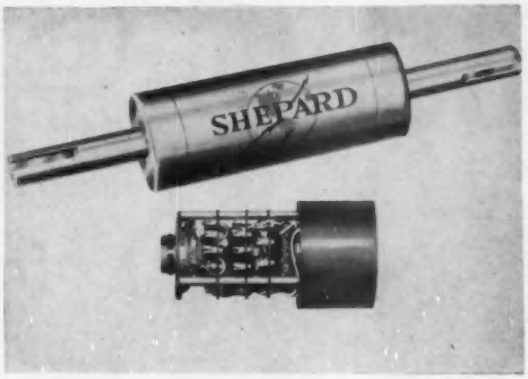
TORQUEMETER features radio link.

The Shepard Torque-Meter is an encapsulated, transistorized device that will measure both torque and horsepower with a high degree of accuracy. Signal information of interest is transmitted from high-speed rotating machinery by radio link. The unit will operate for about 200 hours on a single mercury cell.

Applications include measurement of: torque and horsepower in turbine machinery, thrust or horsepower in jet engines, and horsepower in automobile engines.

Specifications cover a horsepower range of 0 to 5,000, a torque range of 0 to 10,000 lb-in., and operating speeds to 45,000 rpm. System accuracy is within 1 percent of any full-scale reading.—Savage Industries, Inc., Phoenix, Ariz.

Circle No. 2 on reply card



NMR ANALYZER provides permanent record.

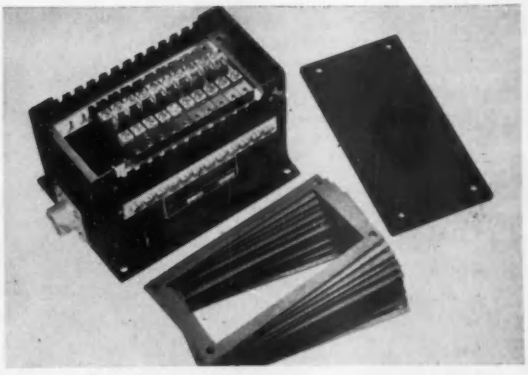
The new Model 104 NMR high-speed moisture analyzer makes quantitative determinations of moisture content in a wide variety of solids (wood pulp, chicle, cotton, cereals, etc.). Other products that can be effectively analyzed by the unit are soap, polyethylene, geological cores, clay, and fibrinogen. It carries out these analyses in from 30 sec to 4 min, as opposed to the 4 hours required by the oven or other conventional methods. Model 104 operates on the principle of nuclear magnetic resonance and is both a research and production instrument. Fast and accurate, it can be operated by an unskilled technician. Samples are not altered in any way, and may even be returned to stock.—Schlumberger Well Surveying Corp., Ridgefield, Conn.

Circle No. 3 on reply card

TEMPERATURE SYSTEM for 12 points.

This resistance thermometry system designed specifically for rigid environmental conditions, such as missile and aircraft testing programs, permits the continuous monitoring of temperatures at 12 points within the vehicle. The photo shows that the plug-in bridges, available for a variety of temperatures and spans, are readily removed. Piled in front of the unit are multilayer gaskets used to seal around the sensor leads. Power comes from the missile (or aircraft) instrumentation supply, and both Stikon and Strapon resistance thermometer elements may be used as sensors. Acceptance tests cover temperature, altitude, humidity, shock, vibration, etc.—Ruge Associates, Inc., Cambridge, Mass.

Circle No. 4 on reply card



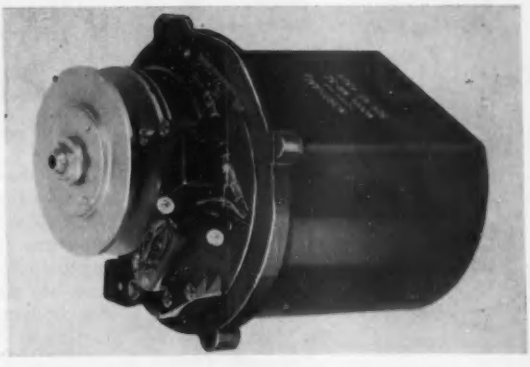
MINIATURE RECORDERS weigh just 4.5 lb.

A new series of four miniature magnetic tape recorders is designed for collecting essential data in guided missiles, rockets, torpedoes, aircraft, and other military vehicles.

Models MR-50 through 53 have ten times the tape capacity of units heretofore available and provide longer running times and higher tape speeds. Higher frequency response is therefore possible. All are seven-track units (six data tracks and one for timing), with a built-in transistorized timing oscillator. Standard tape speeds are 15 and 30 in. per sec.

All units weigh 4.5 lb without armor, and measure 5.3 in. in diam by 7 in. long. They are designed to survive 1,200 g's. —Northam Electronics, Inc., Altadena, Calif.

Circle No. 5 on reply card



Control it with Comvor®

DATA TRANSMISSION TERMINAL

RFL Model 912
Operates over Wire Circuit or Microwave

•

Reliable HIGH-SPEED Continuous Control
of
PUMPS
VALVES
MOTORS
GENERATORS
RELAYS
ETC.

The Model 912 Comvor, an audio frequency shift terminal, is used in the transmission of telemeter, telegraph or control signals over either wire line, microwave, or carrier. Up to 60 individual information channels are available in the audio spectrum.

Reliable frequency shift method of keying is used. All essential controls such as transmitter output level and receiver input level are included.

Each terminal contains its own power supply which provides an additional 60 milliamperes at both the transmitter and receiver for the operation of relays, stepping switches, selector magnets, and other components used in telemetering, control and telegraph applications.

WE CAN HELP YOU
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NEW PRODUCTS

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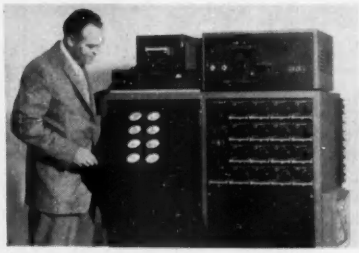
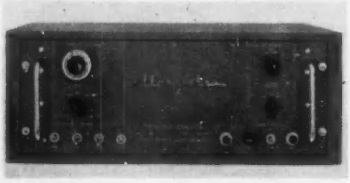


TO 16 CHANNELS

The Type CR-1B Cathode-Ray Recording Oscillograph can simultaneously record up to 16 channels of phenomena at frequencies as high as 100,000 cps on a single 8-in.-wide record. Extremely accurate, simple, and dependable, the unit is a complete high-precision recording system with its own power supplies, preamplifiers, deflection amplifiers, and recorder. As may be seen in the photo, eight dual-gun cathode-ray tubes are used. Traces developed across the tube faces are sharply focused by the optical system and recorded on photographic film or paper. Eight speeds, from 3 to 400 in. per sec, may be selected by means of front-panel pushbuttons which actuate separate magnetic clutches. Continuous records of 400 ft. and shorter ones (from 1 to 50 ft) can be run.—Consolidated Electrodynamics Corp., Pasadena, Calif.

Circle No. 6 on reply card



FAST CONVERTER

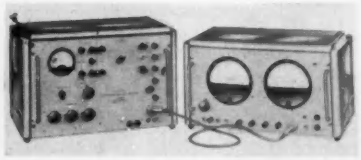
The high-frequency, low-time-constant converter shown here is said to be 10 times faster than other available instruments, and so inherently accurate, says the maker, that it can be used for secondary standard bridge readouts. It can measure fluid-flow transient changes in 0.75 millisec (in contrast to the 200-millisec response ordinarily available), and thus should be useful in tachometry to record hitherto undetected speed changes. Input frequency ranges of from 250 to 2,500 cps can be extended down to 25 cps and up to 10,000 cps. Output voltage into 30 ohms is 6 to 10 volts. The output can be varied to match the output of any type recorder. Unit is available for rack mounting or in a case measuring 10 by 21 by 8 in. Price is $1,500.—Potter Aeronautical Corp., Union, N. J.

Circle No. 7 on reply card

LAB PRECISION

This new battery-operated ac electronic voltmeter, featuring an all-transistor design and printed wiring, is intended for laboratory-precision field applications. Known as the Type 10A, it is compact and light, and can easily be carried in one hand. Voltages from 1 mv full-scale to 300 volts full-scale can be measured in the frequency range of 20 cps to 500 kc. Because of a large meter swing, voltage differences as small as 0.5 percent can be detected. The entire unit measures 6 by 8 by 6 in. and weighs 5 lb.—Consolidated Electrodynamics Corp., Pasadena, Calif.

Circle No. 8 on reply card



AVAILABLE FOR TRIAL

Pictured is a new transfer function analyzer that provides, on two meter dials, all the information required to plot phase and gain diagrams. Frequency range of the instrument is 0.5 to 1,000 cps. So convinced is the manufacturer of the instrument's excellent performance that it is offering prospective users a full week's trial

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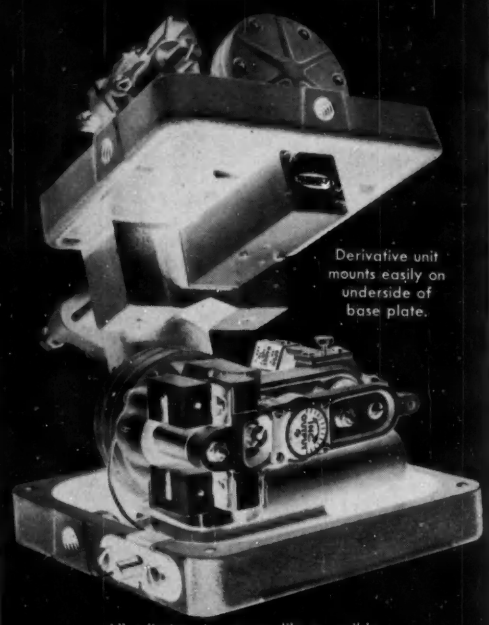
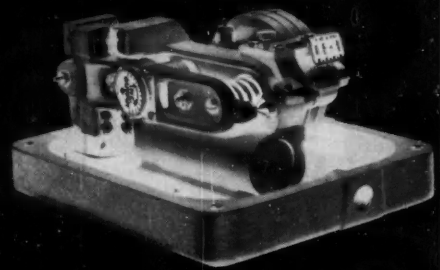
NEW



Derivative unit mounts easily on underside of base plate.

All adjustments are readily accessible, visible and easy to make.



Special "Balanced Beam" design permits mounting in any position without zero shift.

MASONEILAN TEMPERATURE TRANSMITTER

Distinguished by Exclusive Features

Important design differences in this newly developed force-balance transmitter offer advantages in accuracy and dependability. For example:

- **Balanced Beam** design permits mounting in any position without zero shift.
- **Unit subassembly** construction permits removal (for change of range, replacement or maintenance) of thermal system; compensating bellows; feedback bellows; pilot; range span adjustment assembly; derivative unit; gasketless nozzle — any or all without disassembling beam assembly in any way.
- **All adjustments visible and accessible** without disturbing any other part of the mechanism. Range span setting is unaffected by vibration.
- **Protection against damage** is provided for thermal system by a beam stop and the overrange feature; for compensating bellows by built-in stops; for entire unit by rugged weatherproof case.
- **Indicating Receiver Gauge** may be installed directly in manifolded base plate — no piping or tubing required.

A Pressure Transmitter, Too: The temperature transmitter may be readily converted to a pressure transmitter by substitution of a pressure element for the thermal system (within limits imposed by pressure conditions and characteristics of measured fluid).

Write for bulletin or secure details from our nearest office.

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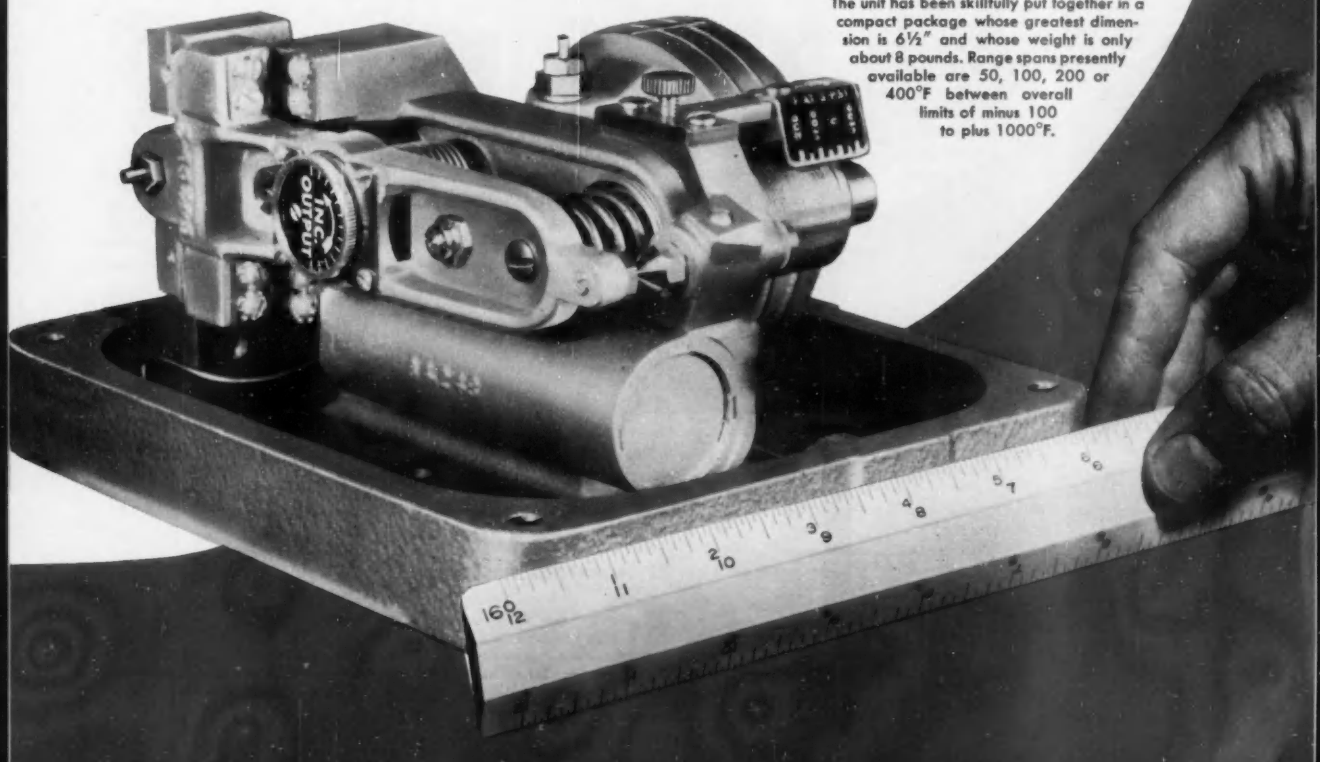
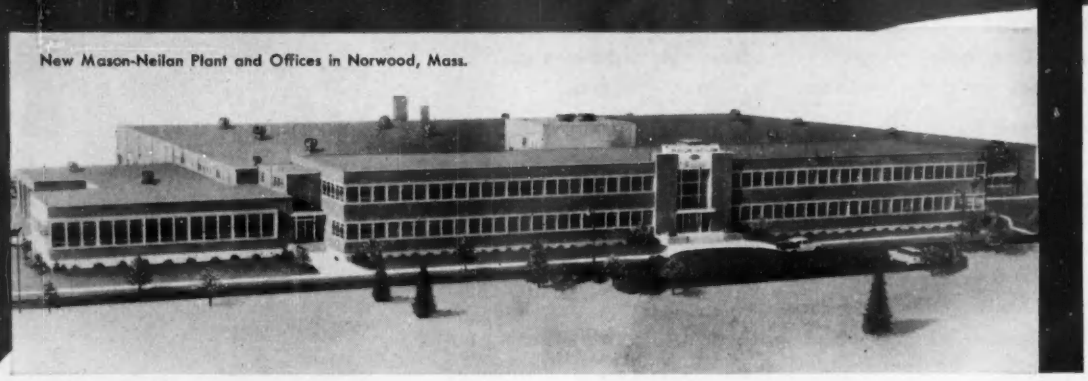


The unit has been skillfully put together in a compact package whose greatest dimension is 6½" and whose weight is only about 8 pounds. Range spans presently available are 50, 100, 200 or 400°F between overall limits of minus 100 to plus 1000°F.

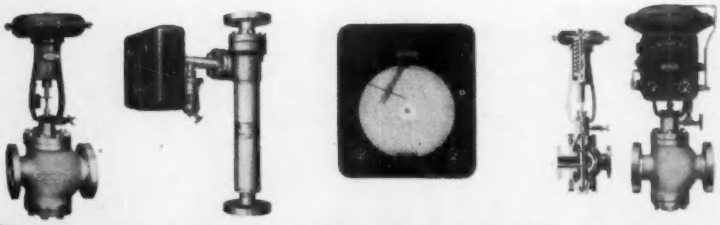


New Mason-Neilan Plant and Offices in Norwood, Mass.

Greatly increased and growing facilities of our new plant permit acceleration of product development for the advancement of

PROCESS CONTROL

to meet the requirements of expanding and increasingly control-conscious industry. New, or improved, realistically-engineered products, now in various stages of development are scheduled to join the Mason-Neilan quality line.



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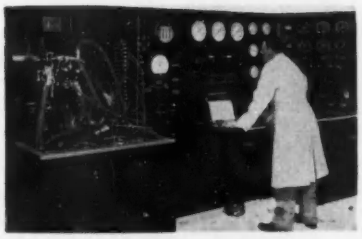
without obligation.–Solartron, North Hollywood, Calif.

Circle No. 9 on reply card

DRIFT-FREE STABILITY

The Model 202B combination dc microvoltmeter and amplifier uses proved chopper circuitry to provide high sensitivity with drift-free stability and high input impedance. Fourteen voltage ranges go from 300 mv to 1,000 volts full-scale. Input impedance is 10 megohms on the 10-mv range and lower, 30 megohms on the 30-mv range, and 100 megohms on the 100-mv range and above. Overall, the instrument will measure as little as 10 mv, and the amplifier alone has a maximum gain of 70 db. An output connector on the front panel provides for use as a low-drift dc amplifier with high gain and very high input impedance. Price, complete with probe, is $350.–Kin Tel, San Diego, Calif.

Circle No. 10 on reply card



FUEL CONTROL TESTS

Shown is a new automatic fuel-control test stand that cuts test time by 30 percent. Outstanding features include a means of automatically programming certain operations of the test stand to specified requirements, and an automatic data-recording system that displays graphically, as the test progresses, the performance curves of the control unit under test. Should these curves show a need for adjustment, the test can be stopped and the adjustment made immediately.–George L. Nankervis Co., Detroit, Mich.

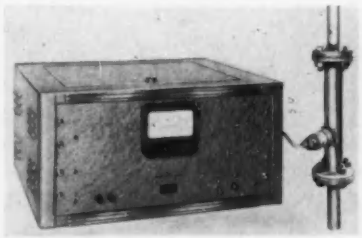
Circle No. 11 on reply card

VERSATILE DESIGN

The Model 83 Signal Generator Series, designed for general laboratory work and rugged field applications where high accuracy in environmental extremes is required, consists of a basic power chassis and five plug-in r-f oscillator assemblies. This arrangement provides the most useful portions of the frequency spectrum compactly and economically. Stability is within 0.1 percent; accuracy within 0.5 percent. –BJ Electronics, Borg-Warner Corp., Santa Ana, Calif.

Circle No. 12 on reply card

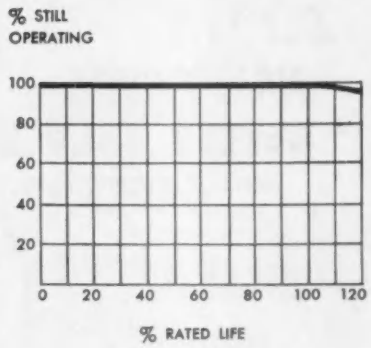
MEASUREMENT & DATA TRANSMISSION



FOR LAMINAR FLOW

The Type FM-100 Electro-Caloric Flowmeter pictured above was designed specifically for measuring mass flow rates of fluids in laminar flow. Measurements are based on the rate of heat transfer through the boundary layer of a liquid or gas flowing through a smooth-bore flow-cell. The measuring elements are completely separated from the fluid by the walls of the flow-cell and thus are protected against chemical and mechanical attack by the stream. Flow-rates of a few pounds per hour and less can be measured with excellent resolution, as can rates of highly viscous materials such as urethane prepolymers, glues, oils, and other hydrocarbons.–Industrial Development Laboratories, Inc., Jersey City, N. J.

Circle No. 13 on reply card



If you want reliable transformers

..don't overlook this old solution

Right now, you demand more from transformers than ever before. You must have high reliability, even at extreme altitudes, and you need smaller lighter units.

Used, and *proved*, for decades, oil-encased transformers should not be forgotten in a search for new methods.

Everyone knows the advantages: effective convection of heat, excellent insulating properties, complete insurance against hidden leaks. Oil-*sealed* types (with a nitrogen bubble) are good, light, high-altitude transformers. Gas-free oil-*filled* types (with a bellows to allow for heat expansion) withstand very high voltage stresses. Except in the smallest sizes, they save space, too.

You can place several high voltage units close together in a single oil-filled case, and save case weight. Those connections moved inside the case no longer need large insulators. Even the units themselves can be smaller. This all adds up—particularly in high altitude service—to interesting savings in space and weight.

We make all sorts of transformers and special assemblies for the communication industry: encapsulated, cast in epoxy or foam, and just potted in pitch. But oil transformers still have an important place.

Whatever type you need, we'll be glad to hear from you. Our facilities in design, production, and quality control are at your service. Our experience, too.

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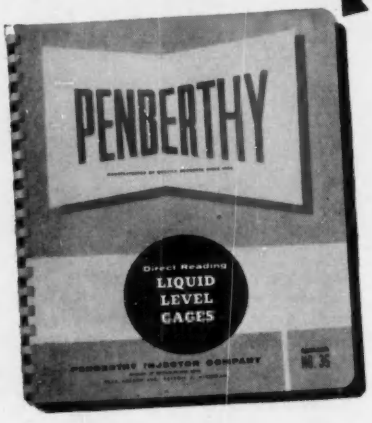
GET THIS HANDY GUIDE TO BETTER VALVES AND GAGES



Shows complete line of Penberthy valves and liquid-level gages for power, petroleum, and process industries. Includes technical data, parts, price lists, and accessories such as:

HEATING AND COOLING GAGES... for accurate readings where liquids must be cooled or heated to obtain exact measurement.

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FROST PREVENTIVE GAGE... eliminates frost build-up... assures dependable visibility. For industries where frosting interferes with accurate readings.

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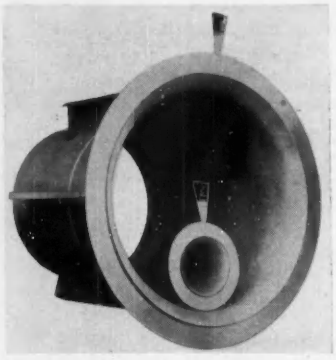
NEW PRODUCTS



FABRICATED NOZZLE

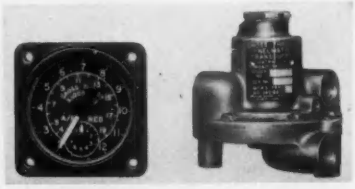
Pictured are two sizes of a new fabricated flow nozzle. Advantages cited by the manufacturer include light weight, low cost, and ease of handling. The new units are about half the weight of forged nozzles of the same size, and can be delivered in half the time. So far, nozzles up to 24 in. in diam have been made, but quotations for a 30-in. model are being prepared. —Penn Instrument Div. of Burgess-Manning Co., Philadelphia, Pa.

Circle No. 14 on reply card

RANGES TO 10,000 PSI–

Here is a pressure transducer that operates continuously in temperatures from minus 65 to plus 300 deg F with less than 1.0 percent deviation in output. A unit for operation at 400 deg F is also available. Vibrations of plus or minus 25 g's can be withstood on all axes, and overpressures up to 50 percent cause no shift in calibration. Pressures range up to 10,000 psi absolute, gage, or differential, with an overall error of less than plus or minus 1.0 percent. Gage and absolute models of this potentiometer-type instrument can be used in systems involving corrosive fluids.–Edcliff Instruments, Monrovia, Calif.

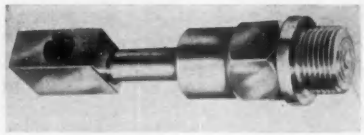
Circle No. 15 on reply card



THRUST METER

The Type 141LA1 all-pneumatic Gross Thrust Measuring System draws its power from compressor discharge pressure. The two components, one engine- and one cockpit-mounted, weigh a total of 1.5 lb. The system presents thrust on a 300-deg arc, 2-in. dial, and has a multiturn vernier for interpolation between 1,000-lb dial graduations. Thrust evaluation is an important pretakeoff factor in jet transport operation.–Manning, Maxwell, & Moore, Inc., Danbury, Conn.

Circle No. 16 on reply card



WATER-COOLED

All exposed parts of this new pressure transducer are of stainless steel and will resist oxidation under very severe conditions. The unit uses the same catenary diaphragm and tubular strain gage as an earlier air-cooled pickup, but has a very efficient water-cooling system that enables the diaphragm to withstand 5,000 deg F. Frequency response is extremely high, and flat to 10,000 cps. Designed for rocket and jet engines, and other high-temperature, high-pressure applications, the transducer is immune to external vibrations and mounts flush so that volume changes are negligible. Models are immediately available for 0 to 1,000 and 0 to 2,000 psi ranges with 99 percent full-scale accuracy.–Detroit Controls Corp., Norwood, Mass.

Circle No. 17 on reply card

LINE TRANSDUCER

A new device called the MOLT (Miniature Optical Line Transducer) is now available for automatic-control, data-reduction, and analog-computing applications. As a curve follower on existing X-Y plotters or strip chart

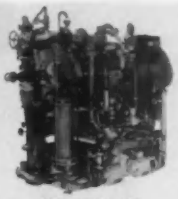
● Manufacturing ●● Manufacturing and product development ●●● Manufacturing, product development and research ○●● Pilot manufacturing, product development and research

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	GPE CAPACITIES
●●	○●●	●●●	●●	●●	●●●	●●●	●●●		●●	●●●	Precision Mechanics, Optical Devices, Ceramics
●●		●●●		●●●	●●●	●●●	●●●		●	●●	Electrical Equipment and Components
●●●	●●●	●●●		●	●●●	●●●	●●●		●●	●●	Electronics
●●●			●●●					●●●	●●		Hydraulics, Liquids Processing, Heat Exchange
	●●●	●●●		●●	●				●●●	●●●	Motion Picture, Photographic, Television and Audio Equipment
●●●	○●●	●●●		●●	●●●	●●●	●●●	●●●	●	●●	Instruments, Servos, Controls: Hydraulic, Pneumatic, Magnetic, Electronic
●●	●●●	●●●		●	●●●	●●●	●●●		●		Aircraft and Missile Guidance, Control, Simulation
●●●	○●●				●●●	●●●	●●●		●		Automatic Computers and Components
●	●●●				●●●	○●●	●●		●	●	Radar, Microwave, Ultrasonics
●●			●●		●●●	●●●					Nuclear Power Components and Controls
●●●	●●●		●●●		●●●	●●●	●●●	●●●			SYSTEMS ENGINEERING

Librascope Desk-Size Computer

Link Aviation F-89D Jet Simulator

GPL Industrial-Institutional TV System



Griscom-Russell Shipboard Distilling Plant

Askania Electro-Jet Power Package

GPE

SYSTEMS ENGINEERING

The GPE Companies are leaders in that small, select group in American industry which is broadly qualified to develop and produce the systems needed today for defense and industry. GPE leadership accounts for some of the most advanced systems in use in business, television, aviation, marine, steel, oil, and other industrial fields.

In Systems Engineering, highly advanced capacities and resources are prerequisite. Yet, no matter how highly advanced, they are of little use if limited to a few areas. Finding optimum solutions to complex systems problems calls for *balanced competences*. And beyond that, success calls for the consistent application of such competences *at every stage* — beginning with research, and extending all the way through development, production and final testing.

No GPE company is limited by the boundaries of its own specialties. The basic GPE operating policy, GPE Coordinated Precision Technology, places at the command of each company in the group all GPE research, development and production facilities, and the skills and experience of the approximately 4000 GPE technical men working in depth in the wide range of advanced capacities indicated in the chart above.

Behind each group working on a specific problem in one GPE company stands the whole group of GPE scientists, engineers and technicians with the answers — or the knowledge that will find the answers — to questions underlying and related to that problem. To the customers of GPE Companies this means that the concept and development of equipment, components and systems are not restricted or distorted by traditional allegiance to specific competences.

The five systems illustrated, while products of different GPE companies, are all examples of the consistent application of balanced competences, achieved through GPE coordination. For brochure describing GPE Coordinated Precision Technology and the work of the GPE Companies, or help on a specific problem, write: General Precision Equipment Corporation, 92 Gold Street, New York 38, N. Y.

GENERAL PRECISION EQUIPMENT CORPORATION

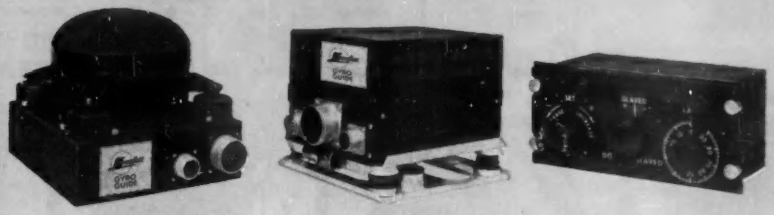
THE GPE PRODUCING COMPANIES

(I) ASKANIA REGULATOR COMPANY (V) GENERAL PRECISION LABORATORY INCORPORATED (III) GRAFLEX, INC.
(IV) THE GRISCOM-RUSSELL COMPANY (X) THE HERTNER ELECTRIC COMPANY (XI) KEARFOTT COMPANY, INC.
(VII) LIBRASCOPE, INCORPORATED (VIII) LINK AVIATION, INC. (IX) SHAND AND JURS CO. (II) SIMPLEX EQUIPMENT CORPORATION
(VI) THE STRONG ELECTRIC CORPORATION

PRECISION SYSTEMS AND COMPONENTS *in production*

NAVIGATION SYSTEMS

Kearfott Systems include 3 gyro, 3 and 4 gimbal platforms. They provide precise azimuth and vertical reference. Also Directional Gyro Compass Systems.



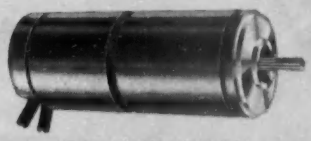
The Gyro Guide System shown provides Latitude Corrected Gyro and Magnetic Slaved Heading information. Weighs 20 lbs. Max. random drift 3°/hour.

GYROS, SERVO MOTORS, SYNCHROS

Kearfott produces a complete line of gyros, servo motors, and synchros to satisfy every aircraft control requirement.

FLOATED INTEGRATING GYRO

3 Gyro Platforms, Floated Rate Integrating Gyros, Vertical, Free, Directional, Rate Gyros and Gyro operated rate switches—compact, lightweight, hermetically sealed.



SERVO MOTORS, SYNCHROS

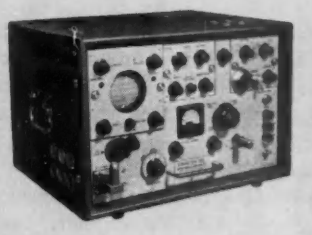
High torque, low inertia Servo motors, Servo-motor-Generators, inertial and viscous damped Servo motors 3/4" to 1-3/4" diameter, Synchro Transmitters, Control Transformers, Resolvers, Repeaters and Differentials in size 8, 11 and 15.

MICROWAVE EQUIPMENT

Kearfott offers engineering-design service, manufacturing facilities and a wide experience in the production of microwave components and test sets.

COMPONENTS

Including attenuators, directional couplers, crystal mixers, twists and tees for S, C, Xb, X and Ku bands.



TEST SETS (for X, C, and Ku)

A four-in-one instrument for functional testing of radar or beacon. Includes Wavemeter, Spectrum Analyzer, Power Monitor, and signal generator.

Bulletins giving physical and technical data on the various Kearfott Products will be sent on request. The Kearfott organization is available to assist in the development and manufacture of other precision components you may require.

KEARFOTT COMPANY, INC., Little Falls, N. J.

Sales and Engineering Offices: 1378 Main Ave., Clifton, N.J.
Midwest Office: 25 West Calendar Avenue, La Grange, Ill.
South Central Office: 6211 Denton Drive, Dallas, Texas
West Coast Office: 253 N. Vinedo Avenue, Pasadena, Calif.

WESTERN MANUFACTURING DIVISION:
13845 Oxnard Street, Van Nuys, Calif.

Kearfott

GPE A SUBSIDIARY OF GENERAL PRECISION EQUIPMENT CORPORATION

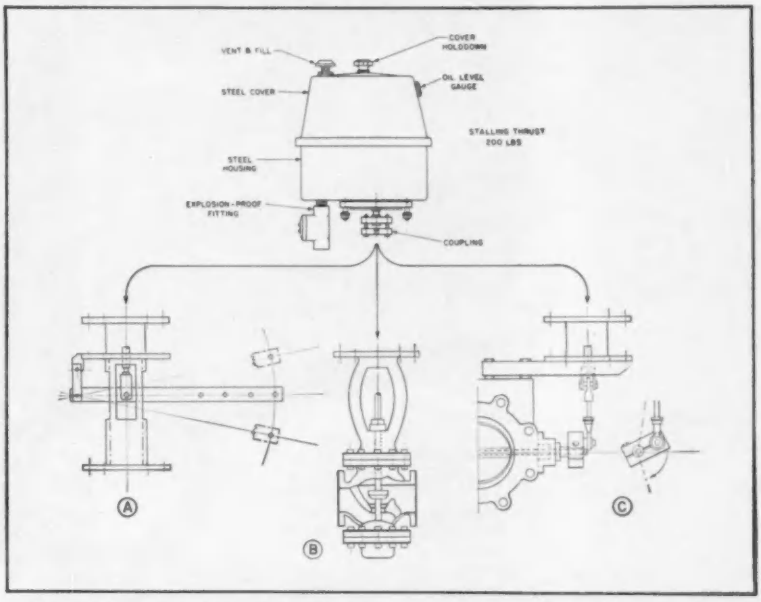
Askania Regulator Company NEWS

Automatic Controls for
PRESSURE, FLOW and COMBUSTION

As demonstrated at the ISA show

A NEW ASKANIA FINAL CONTROL ELEMENT

The Model RF-697 Electrohydraulic Valve Actuator



For Valves Requiring Less Than 200 lbs. Thrust

The Askania Model RF-697 Electrohydraulic Valve Actuator comprises a self-contained unit designed for proportional-position control, using signals from an electronic controller, manual station or directly from a measuring element.

Smaller, more compact and designed for operating valves with ½ to 1½ inch stroke requiring less than 200 lb. thrust, it operates from low level a-c or d-c signals. The d-c range is 1-5 or 4-8 milliamperes. For operation on a-c signals internal rectifiers are provided.

Design Provides Outstanding Operating Advantages

Exclusive design assures *stability*, *fast response*, and *dependable operation* marked by an ABSOLUTE MINIMUM OF MAINTENANCE. Note these important operating advantages:

1. Entirely self-contained
2. Operates directly from controller without relays or converters
3. Mechanically simple
4. Easy to mount on valve—simple to install
5. Competitively priced
6. Designed to meet Underwriters' Laboratories' explosion-proof requirements for Class I, Group D, Division 1 service.

Wide Valve Mounting Adaptability

The Model RF-697 Valve Actuator can be mounted on practically any valve. Typical valve mountings are shown at the right, above:

A. Mounted to provide a lever arm
B. Mounting for sliding-stem valve
C. Mounted on butterfly valve

Important Specifications

Valve Stem Speed...5 inches per minute at 150 lb. load
Valve Stem Stalling Thrust...200 lbs.
Valve Stem Stroke...½" to 1½"
Input Coil Resistance...Standard coil resistance approximately 12,000 ohms at operating temperature.

Send for Application Bulletin No. 38.3 for complete information on this new Electrohydraulic Valve Actuator. Write Askania Regulator Company, 266 E. Ontario Street, Chicago, Illinois.

ASKANIA REGULATOR COMPANY
"CONTROLS FOR INDUSTRY"
HYDRAULIC, ELECTRONIC CONTROLS & SERVOS, GENERAL SYSTEMS, ENGINEERING & COMPUTER SERVICE, VALVE ACTUATORS & CYLINDERS

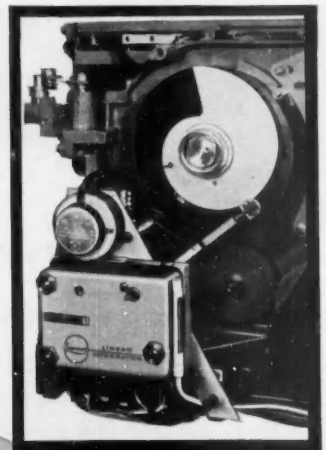
A SUBSIDIARY OF
GENERAL PRECISION EQUIPMENT CORPORATION

GPE

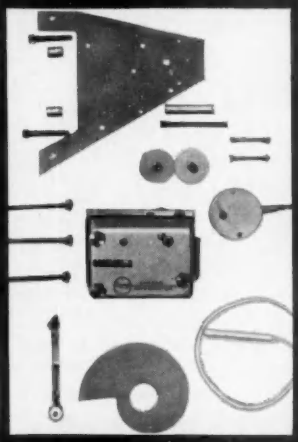
THE LIBRASCOPE

Model 25 COMPUTING LINEAR INTEGRATOR

for flow totalization • temperature recording averaging • area computations in gas analysis procedures

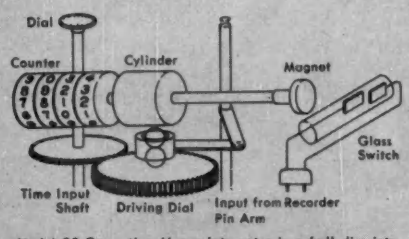


Model 25 Librascope Computing Linear Integrator mounted on a Strip Chart Recorder. In this position it accepts the output of the transducer or the recorder pen motion as an input.



Typical Adapter Kit of Model 25 Librascope Computing Linear Integrator with parts. These include baseplate, case, disc, roller, linkages, input shaft, bearings and carriage guides.

Eliminates manual integration of recording data.
Provides continuous integration.
Direct reading and also remote reading through electrical impulse output.
Fits all Standard or Miniature Strip Chart Recorders.



Model 25 Computing Linear Integrator is a *ball disc integrating mechanism* assembled with a counter and an electrical pulse output switch for remote recording.

The Model 25 *Librascope Computing Linear Integrator* is designed to provide a fast, accurate, reliable, continuously integrated total of data as it is being recorded or presented. (The Model 25 Computing Linear Integrator ends inaccuracies of totalizing by eliminating manual integration.) The Model 25 can be installed on any device having shaft rotation or displacements as an output.

SPECIFICATIONS

Shaft Rotation — 0° — 100°
Range — 0% — 100%
Input Shaft Torque — 0.1 in. oz.
Outputs —
Mechanical counter — 4 digits
Electrical Pulse
DC Volts: 28 — amps.: 0.5
AC Volts: 110 — amps.: 0.5
Size — 3.0" x 4.38"
Weight — 1.5 (lbs.)
Computer is sealed against dust.

Computors, Controls, Components

Representatives located in principal cities

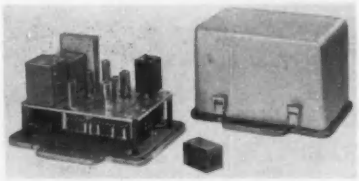
LIBRASCOPE
A SUBSIDIARY OF GPE

Librascope, Incorporated • 808 Western Ave. • Glendale, California

Installation kits are designed to fit any standard or miniature chart recorders.
For detailed information of Model 25, write for Computing Linear Integrator Bulletin just released.

recorders, the MOLT serves as part of an arbitrary function generator for analog computing or automatic machine tool control. Edge finding, counting small objects, and extremely sensitive limit switching are other applications. In operation, a medical-probe-type lamp produces a beam of light that is channeled through a clear plastic body and focused in a well-defined spot directly beneath an end-sensitive photo-conductive cell. The reflected light causes the resistance of photocell to be characteristic of the surface that the MOLT "sees". Unit weighs less than ½ oz.–Munro Electronic Associates, Mansfield, Mass.

Circle No. 18 on reply card



FOR REMOTE CONTROL

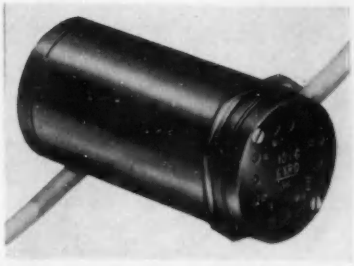
When keyed by switches for control applications or pulse-width signaling transducers for metering, the Model 55 Transmitter (covered right) provides two independent signaling tones in the frequency range of 2.8 to 100 kc. The receiver (uncovered left) provides two independent regulated outputs of 20 to 50 ma for recording transmitted data or, by means of plug-in hermetically sealed DPDT relays, up to 20 amp at 250 volts for on-off control over each channel. Designed for telephone lines or cables with up to 20 db attenuation between associated transmitter and receiver, these plug-in relays can control a 1-hp motor without auxiliary contacts. They are intended for continuous unattended service in remote locations.–Moore Associates, Redwood City, Calif.

Circle No. 19 on reply card

BRIDGE STABILIZED

The Series BRJ bridge-stabilized T/C reference junction measures only 10 by 10 by 15 in. and weighs only 25 lb. but provides a more precise controlled temperature reference for multi-channel thermocouple measurements than ice bath and cold junction compensators. "Three-wire" junctions allow a choice of thermocouple material in each channel (up to 48 are available in cabinet or rack-mounting standard models). Long-term stability within ½ deg F is obtained with an integral resistance-bridge temperature-sensing system and magnetic-amplifier-controlled heater. Reference temperature may be set at any value from 25 deg above ambient to 250 deg F.–Pace Engineering Co., North Hollywood, Calif.

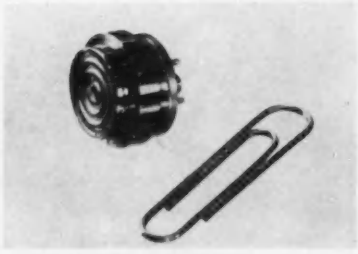
Circle No. 20 on reply card



FLOATED GYRO

One of a new series of high-precision, subminiature floated integrating gyros, this 1-in.-in-diam unit is designed for missiles and other applications where space and weight are at an absolute premium. The gyros are fully floated to minimize friction and uncertainty torque and to improve vibrational shock resistance. Power requirement is less than ½ watt. Connections are made through 11-pin plugs at each end of the gyro. Total weight, exclusive of connectors, is only 3¾ oz.–Reeves Instrument Corp., New York, N. Y.

Circle No. 21 on reply card



MINIATURE PICKUP

Shown is one of a new line of flange-mounted pressure pickups, which combine high output and small size with unusual accuracy. Output varies from 25 to 100 mv full-scale, depending on the pressure range. Minimum output is 5 mv per volt of excitation; maximum 10 mv per volt. The unit has a diaphragm diameter of ½ in., a flange diameter of ⅝ in., an overall length of 1⅛ in., and a weight of just 7 grams.

HOLTZER -CABOT

Instrument Control Motors

The R-24 4-pole induction motor, with reversible rotation, is adaptable to a wide variety of applications. Typical uses are in servo mechanisms; as a balancing motor in recording instruments, and as a control motor for voltage regulators. When operated 2 phase, it can be controlled electronically; it can also be run single phase as a permanent split capacitor motor.

Specifically engineered to operate effectively with other engineering apparatus. Also available with gear-train. Send coupon below for additional information.

HOLTZER-CABOT MOTOR DIVISION
NATIONAL PNEUMATIC CO., INC.
125 Amory Street, Boston 19, Mass.

GENTLEMEN: ☐ Please send me data sheets on the Holtzer-Cabot R-24 Motors.

☐ Please have representative call on..... (date)

Name.....

Company.....

Street.....

City.....Zone.....State.....

FIRST AND ONLY... MINIATURE TWO PEN 5" RECORDING POTENTIOMETER

Transistor Amplifiers

exclusive from...

westronics®
INCORPORATED

$1195.00*

THE ULTIMATE IN AN ACCURATE, READABLE, MINIATURE RECORDING POTENTIOMETER, WITH THESE ADVANCED FEATURES

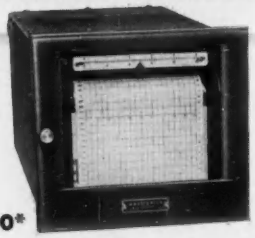
- 5-inch strip chart record.
- Two pens, each traveling the full 5 inches.
- 1-second maximum balancing time.
- Table top or panel mounting.
- Panel space 9⅝" W x 8½" H
- Margin marker pens.
- Paper supply indicator front of recorder.
- Ball bearings in pen drive system.
- New concept in front set limit switches.
- 0.5% accuracy on both pens.
- Completely transistorized amplifiers, no vacuum tubes.
- MV or TC Calibration
- Minimum Span: 1 MV
- Standardization: Mercury cell.
- Simple sub-assembly type construction for easy maintenance. (Entire recorder rolls forward out of case.)

PLUS THESE OPTIONAL FEATURES:

- One front set SPDT switch and 3 SPDT back set switches each independently adjustable over the entire range on each pen.
- Transmitting slidewires.
- Selsyn motor chart drive.
- 3 speed quick change chart drive.
- Left and/or right margin marking pens.

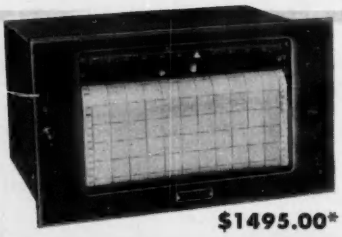
WESTRONICS RECORDING POTENTIOMETERS FOR EVERY NEED

One Pen Miniature 5" Recording Potentiometer



- 5" strip chart record.
- Continuous Automatic Standardization with electron tube amplifiers.
- Requires only 9⅝" by 8½" panel space.
- Accuracy better than 0.5%.
- One second full scale pen travel.
- Weighs less than 25 pounds.

$490.00*



Two Pen 11" Recording Potentiometer

- 11" strip chart recorder (12" overall width).
- Completely transistorized amplifiers.
- Reduced maintenance.
- Small size.
- Immediate recording . . . no warm-up time.
- Optional synchronous motor or Selsyn motor chart drive.

$1495.00*

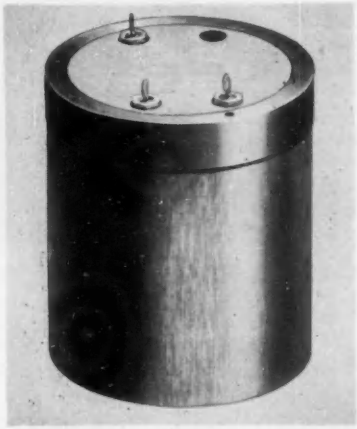
***BASE PRICE**

WESTRONICS® INCORPORATED

NEW PRODUCTS

Accuracies to within 0.5 percent full-scale have been achieved. Temperatures may vary from minus 100 to plus 300 deg F.—Dynamic Instrument Co., Cambridge, Mass.

Circle No. 22 on reply card



NEEDS NO HEATER

This Model 7-31 Accelerometer offers temperature controlled damping without using a heater. Temperature range is minus 55 to plus 200 deg F, and the calibration shift is less than 1.0 percent. Acceleration ranges are plus or minus 0.5 to 150 g's, with maximum resolution of 0.25 percent. A unique mass suspension reduces transverse vibration sensitivity and permits greater side loads without damaging or upsetting calibration. Case dimensions are $1\frac{7}{8}$ in. in diam by 2.22 in. long.—Edcliff Instruments, Monrovia, Calif.

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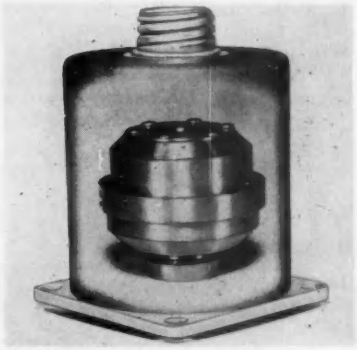
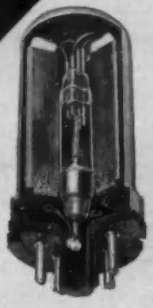


LIGHTWEIGHT MOTOR

The composite photo above shows a new rate gyro, Model RG15-0102-1, as

CLARE RELAYS and AUTOMATION

Cutaway view of CLARE Mercury-Wetted-Contact Relay, two of which are used by AccuRay to control cigarette making process.



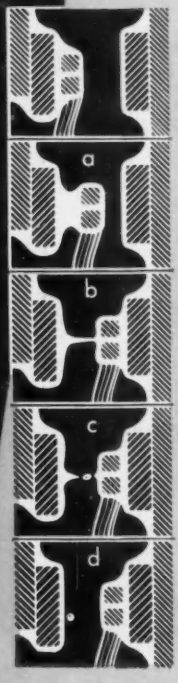
How *AccuRay* uses long-life CLARE Mercury-Wetted-Contact Relays to provide accurate, continuous and automatic control of a manufacturing process

Actuated by variations in the electric current set up by a constant intensity beam of radiation through a cigarette "rod," two CLARE Mercury-Wetted-Contact Relays help the AccuRay Cigarette-Gauge controller to proportion the weight of cigarettes as they are being produced.

In this way AccuRay, a revolutionary precision process control system, uses electronics to provide automatic control of cigarette and other manufacturing production processes.

Engineers of Industrial Nucleonics Corporation, makers of this new process control, picked CLARE Relays to perform these important functions because only these relays gave the long life and low maintenance required. These machines wrap and cut 20 cigarettes a second, day and night, day after day.

With a service life of billions of operations* it is no wonder this relay has become the first choice of hundreds of leading designers of computing, data-processing and control equipment. For complete information write for Bulletins 120 and 122 to C. P. Clare & Company, 3101 Pratt Blvd., Chicago 45, Illinois. In Canada: 659 Bayview Avenue, Toronto 17. Cable address: CLARELAY.



Drawings (left) from high-speed photographs show the cycle. (a) Filament of mercury forms between the contacts as they separate. (b) This becomes narrower in cross section and (c) finally parts at two points, allowing globule of mercury to fall out. Mercury flows up the capillary path, replaces amount lost, restores the equilibrium. (d) The momentary bridging of the parting contacts—and the extremely fast break that ends it—minimizes the arc and adds greatly to contact load capacity. Contact closure between the two liquid surfaces bridges mechanical bounce and prevents any chatter from appearing in the electrical circuit.

** More than two years ago a life test started on a group of these relays carrying a full contact load of 5 amperes at 50 volts d-c with suitable spark suppression. They have been operating continuously ever since at 5,184,000 operations a day. They have now passed the 4 billion mark—and the end is not yet in sight.*

CLARE RELAYS

FIRST in the industrial field

® Industrial Nucleonics Corporation, Columbus, Ohio

FIRST AND ONLY... MINIATURE TWO PEN 5" RECORDING POTENTIOMETER

Transistor Amplifiers

exclusive from...

westronics®
INCORPORATED

$1195.00*

THE ULTIMATE IN AN ACCURATE, READABLE, MINIATURE RECORDING POTENTIOMETER, WITH THESE ADVANCED FEATURES

- 5-inch strip chart record.
- Two pens, each traveling the full 5 inches.
- 1-second maximum balancing time.
- Table top or panel mounting.
- Panel space 9⅝" W x 8½" H
- Margin marker pens.
- Paper supply indicator front of recorder.
- Ball bearings in pen drive system.
- New concept in front set limit switches.
- 0.5% accuracy on both pens.
- Completely transistorized amplifiers, no vacuum tubes.
- MV or TC Calibration
- Minimum Span: 1 MV
- Standardization: Mercury cell.
- Simple sub-assembly type construction for easy maintenance. (Entire recorder rolls forward out of case.)

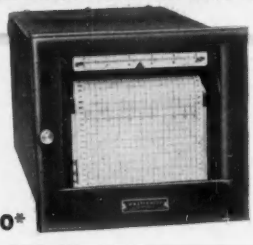
PLUS THESE OPTIONAL FEATURES:

- One front set SPDT switch and 3 SPDT back set switches each independently adjustable over the entire* range on each pen.
- Transmitting slidewires.
- Selsyn motor chart drive.
- 3 speed quick change chart drive.
- Left and/or right margin marking pens.

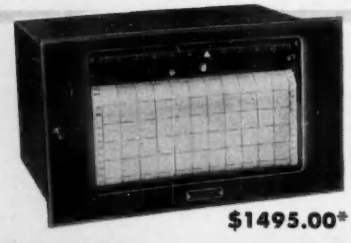
WESTRONICS RECORDING POTENTIOMETERS FOR EVERY NEED

One Pen Miniature 5" Recording Potentiometer

- 5" strip chart record.
- Continuous Automatic Standardization with electron tube amplifiers.
- Requires only 9⅝" by 8½" panel space.
- Accuracy better than 0.5%.
- One second full scale pen travel.
- Weighs less than 25 pounds.



$490.00*



$1495.00*

Two Pen 11" Recording Potentiometer

- 11" strip chart recorder (12" overall width).
- Completely transistorized amplifiers.
- Reduced maintenance.
- Small size.
- Immediate recording . . . no warm-up time.
- Optional synchronous motor or Selsyn motor chart drive.

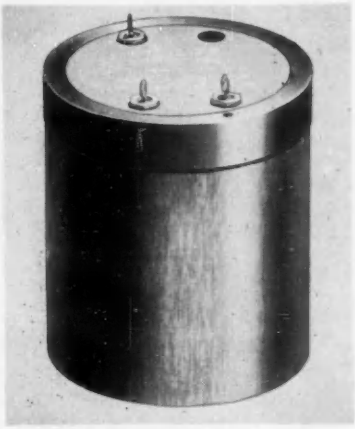
***BASE PRICE**

westronics INCORPORATED
[illegible] FORT WORTH, TEXAS • PHONE WAlnut 2-8312

NEW PRODUCTS

Accuracies to within 0.5 percent full-scale have been achieved. Temperatures may vary from minus 100 to plus 300 deg F.—Dynamic Instrument Co., Cambridge, Mass.

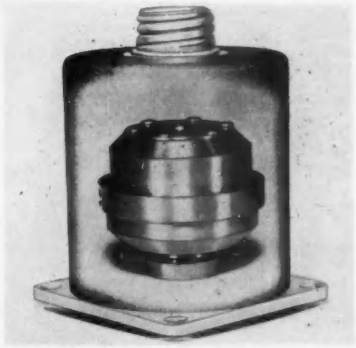
Circle No. 22 on reply card



NEEDS NO HEATER

This Model 7-31 Accelerometer offers temperature controlled damping without using a heater. Temperature range is minus 55 to plus 200 deg F, and the calibration shift is less than 1.0 percent. Acceleration ranges are plus or minus 0.5 to 150 g's, with maximum resolution of 0.25 percent. A unique mass suspension reduces transverse vibration sensitivity and permits greater side loads without damaging or upsetting calibration. Case dimensions are $1\frac{7}{8}$ in. in diam by 2.22 in. long.—Edcliff Instruments, Monrovia, Calif.

Circle No. 23 on reply card



LIGHTWEIGHT MOTOR

The composite photo above shows a new rate gyro, Model RG15-0102-1, as

CLARE RELAYS and AUTOMATION

Cutaway view of CLARE Mercury - Wetted - Contact Relay, two of which are used by AccuRay to control cigarette making process.

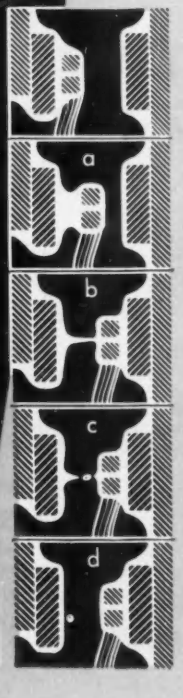
How *AccuRay* uses long-life CLARE Mercury-Wetted-Contact Relays to provide accurate, continuous and automatic control of a manufacturing process

Actuated by variations in the electric current set up by a constant intensity beam of radiation through a cigarette "rod," two CLARE Mercury-Wetted-Contact Relays help the AccuRay Cigarette-Gauge controller to proportion the weight of cigarettes as they are being produced.

In this way AccuRay, a revolutionary precision process control system, uses electronics to provide automatic control of cigarette and other manufacturing production processes.

Engineers of Industrial Nucleonics Corporation, makers of this new process control, picked CLARE Relays to perform these important functions because only these relays gave the long life and low maintenance required. These machines wrap and cut 20 cigarettes a second, day and night, day after day.

With a service life of billions of operations* it is no wonder this relay has become the first choice of hundreds of leading designers of computing, data-processing and control equipment. For complete information write for Bulletins 120 and 122 to C. P. Clare & Company, 3101 Pratt Blvd., Chicago 45, Illinois. In Canada: 659 Bayview Avenue, Toronto 17. Cable address: CLARELAY.



Drawings (left) from high-speed photographs show the cycle. (a) Filament of mercury forms between the contacts as they separate. (b) This becomes narrower in cross section and (c) finally parts at two points, allowing globule of mercury to fall out. Mercury flows up the capillary path, replaces amount lost, restores the equilibrium. (d) The momentary bridging of the parting contacts—and the extremely fast break that ends it—minimizes the arc and adds greatly to contact load capacity. Contact closure between the two liquid surfaces bridges mechanical bounce and prevents any chatter from appearing in the electrical circuit.

More than two years ago a life test started on a group of these relays carrying a full contact load of 5 amperes at 50 volts d-c with suitable spark suppression. They have been operating continuously ever since at 5,184,000 operations a day. They have now passed the 4 billion mark—and the end is not yet in sight.

CLARE RELAYS

FIRST in the industrial field

® Industrial Nucleonics Corporation, Columbus, Ohio

Trans

SILICON DIODES

FEATURES

- Recovery times under .15 μsec
- High voltage ratings
- Operation up to 200°C
- High Inverse Resistance
- Subminiature size

MILITARY AND HIGH CONDUCTANCE TYPES

RATINGS AT 150°C AMBIENT			
Type	Maximum Inverse Operating Voltage (volts)	Maximum Average Forward Current (ma)	Maximum Inverse Current (μa) @ V
IN457*	60	25	5 @ 60
IN458*	125	25	5 @ 125
IN459*	175	25	5 @ 175
IN486A	225	50	25 @ 225
IN488A	380	50	25 @ 380

*JAN Types

HIGH FREQUENCY AND FAST SWITCHING TYPES

RATINGS AT 25°C			
Type	Maximum Inverse Operating Voltage (volts)	Maximum Average Forward Current (ma)	Inverse Recovery Time (μsec)
IN251*	30	75	.15
IN252	20	100	.15
SG213	200	30	.3
SG223	200	55	.5
SG228	200	80	1

*JAN Types

Write for Bulletin TB1350

GERMANIUM DIODES

FEATURES

- Complete Reliability
- Superior Forward Conductance
- Higher Inverse Resistance
- More Uniform Characteristics
- Greater Ruggedness

SPECIFICATIONS AND RATINGS AT 25°C				
Type	Forward Current at + 1V (ma)	Inverse Current at Specified Voltage (μa @ V)	Max. Oper. Voltage (volts)	Description
IN270	200	100 @ −50	80	JAN TYPES
IN277	100	250 @ −50 75 @ −10 @ 75°C	100	
IN276	40	100 @ −50	70	
IN281	40	500 @ −50 30 @ −10	60	
IN126	5	500 @ −50 30 @ −10	60	
IN127	5	300 @ −50 25 @ −10	100	
IN198	5	250 @ −50 75 @ −10 @ 75°C	50	
IN283	200	20 @ −10	20	COMPUTER TYPES
T16G	40	100 @ −50 20 @ −10	60	
IN278	20	125 @ −50 @ 75°C	50	HI-TEMPERATURE TYPES
T22G	40	20 @ −10 @ 75°C	15	
T9G	100	20 @ −50 2 @ −10	60	HI-RESISTANCE TYPES
IN67A	5	50 @ −50 5 @ −5	80	

Other JAN types: IN38A, IN69, IN70, IN81, IN128

Write for Bulletin TB1300 & TB1319

SILICON Power

FEATURES

- Reliability at High Temperature
- High Power Handling Ability
- High Efficiency
- Rugged Construction
- Hermetically Sealed

MINIATURE TYPES

RATINGS AT 150°C AMBIENT			
Type	Peak Recurrent Inverse Voltage (volts)	Maximum Average Forward Current (ma)	Maximum Inverse Current (ma)
TJ10A	100	200	.5
TJ25A	250	200	.5
TJ40A	400	200	.5

SILICON RECTIFIER STACKS

RATINGS AT 125°C AMBIENT			
	DC Output		
Circuit	Voltage (volts)	Current (amps)	Stack Designation
6 φ Star	150	30	TL6S1A1/TR352
3 φ Bridge	325	18	TL6F1A1/TR352
3 φ Halfwave	1120	1.2	TD12Y6B1A4
1 φ Bridge	748	1.2	TD12B4C1A3
1 φ Center Tap	250	3.0	TD12C4C3A2

SILICON VOLTAGE REGULATORS and REFERENCES

FEATURES

- Excellent long-term stability
- High current handling ability
- Operation to 150°C
- Extended operating current range
- Small size, easy mounting
- Hermetically sealed

Reference assemblies are available with temperature coefficients to .002%. They are also available with voltage tolerances to 1% from 10 to over 100 volts. The assemblies are encapsulated in a miniature axial lead package.

"Leadership in semiconductors"

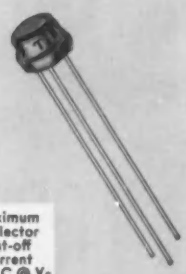
itron

SILICON TRANSISTORS

HIGH FREQUENCY TYPES

FEATURES

- Low I_{co}, typically under .02 μa
- Operation to 175°C
- Power Ratings of 200 mw
- High Frequency Operation
- Welded Hermetic Seal



Type	Minimum Common Emitter Current Gain β	Maximum Collector Voltage V_{CE} Peak (volts)	Typical Cut-off Frequency (mc)	Maximum Collector Cut-off Current @ 25°C @ V_C Max. (μa)
ST12	40	15	16	.5
ST32	40	30	16	.5
ST11	20	15	13	.5
ST31	20	30	13	.5
ST10	10	15	9	.5
ST30	10	30	9	.5

Write for Bulletin TE1353

RECTIFIERS

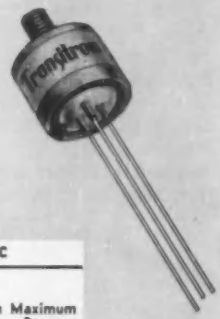
Type	Peak Recurrent Inverse Voltage (volts)	Maximum Average Forward Current (ma)	Maximum Inverse Current (ma)
RATINGS AT 150°C CASE TEMPERATURE			
MILITARY TYPES			
1N253	95	1000	.1
1N254	190	400	.1
1N255	380	400	.15
1N256	570	200	.25
STUD MOUNTED TYPES			
TM47	400	3000	.5
TM64	600	1000	.5
MEDIUM POWER TYPES (amps)			
1N250A	200	20	5
TR301	300	10	5
TR402	400	20	5
HIGH POWER TYPES (amps)			
1N412A	100	35	5
TH402	400	35	5

Write for Bulletin TE1342 & TE1351

GERMANIUM Power TRANSISTOR

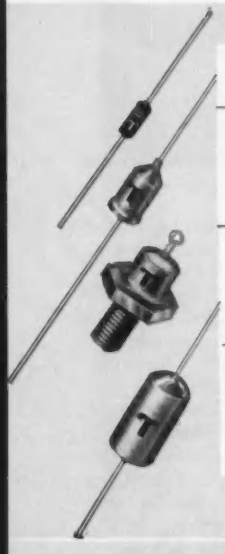
FEATURES

- Operation to 85°C
- Linearity at High Currents
- Up to 10 watts Dissipation
- Low Thermal Resistance
- Small Size
- Hermetically Sealed



TYPE	Minimum DC Common Emitter Current Gain (β @ Ic)	Maximum Collector Voltage V_{CE} Peak (volts)	Maximum Collector Current (amps)	Maximum Power Dissipation (watts)
SPECIFICATIONS AND RATINGS AT 25°C				
2N83A	8 @ 1.0A	60	3	10
2N83	8 @ .5A	60	2	10
2N84A	12 @ 1.0A	45	3	10
2N84	12 @ .5A	45	2	10

Write for Bulletin TE1320



Type	Voltage Range (volts)	Maximum Dynamic Resistance (ohms)	Maximum Current @ 25°C (ma)	Maximum Current @ 125°C (ma)
Subminiature				
SV-5	4.3- 5.4	55	50	10
SV-7	6.2- 8	8	30	6
SV-11	9.0-12.0	50	20	4
SV-15	13.5-18	120	14	3
SV-24	20 -27	300	10	2
Miniature				
SV-804	4.3- 5.4	55	150	30
SV-806	6.2- 8	8	90	18
SV-810	9 -12	50	60	12
SV-815	13.5-18	120	40	8
SV-824	20 -27	300	27	5
Power			55°C (amps)*	(ma)*
SV-904	4.3- 5.4	.5	2.0	500
SV-906	6.2- 8	.8	1.2	300
SV-910	9 -12	1.5	.8	200
SV-915	13.5-18.0	3	.6	150
SV-924	20 -27	8	.4	100

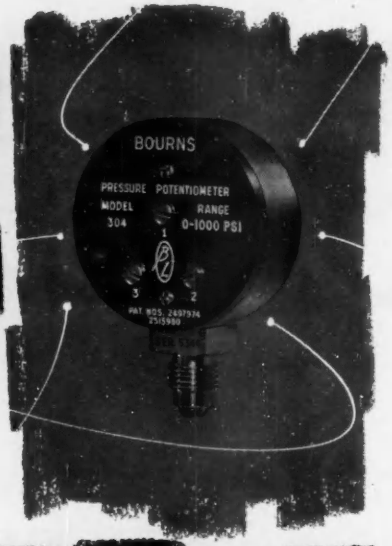
Write for Bulletin TE-1352
*Case temperature ratings

Transitron

electronic corporation

wakefield, massachusetts CRystal 9-4500

BOURNS



MODEL 304

GAGE PRESSURE TRANSDUCER

—high performance in miniature size

Only 1⅝" in diameter... ¾" thick, this is an exceptionally small gage pressure potentiometer. Its miniature size and compact configuration permits use in ground and airborne installations—in control telemetering or remote recording circuits—wherever space is at a premium.

Time proved performance. This is a fully integrated instrument built for high reliability under extreme environmental conditions. The dependable Bourns Bourdon tube assembly and linkage system provide exceptional shock, vibration and acceleration characteristics ... linearity and hysteresis are excellent. Units are designed to meet or exceed most government specifications for airborne equipment.

The Bourns Model 304 weighs about 2 ounces. It operates with a high-level AC or DC signal. Pressure ranges: from 0-100 to 0-5000 psi. Three Bourdon tube materials are available:

Beryllium copper—the standard construction—for non-corrosive fluids. Measures air, Freon, oil, and other common media.

Stainless steel—permits corrosive fluids such as fuming nitric acid to be applied within the tube.

Ni-Span-C—provides low temperature error for versatility of application.

Complete data in Bulletin No. 304.

ABSOLUTE AND DIFFERENTIAL PRESSURE

In addition to the Model 304, Bourns manufactures a complete line of high pressure transducers in absolute and differential ranges, for use with corrosive or non-corrosive fluids. Request Bulletin No. 70456.

MODEL 704—differential pressure type with stainless steel Bourdon tube

MODEL 706—differential pressure type with Beryllium copper Bourdon tube

MODEL 705—absolute pressure type for use with clean, non-corrosive media

COPR. BL

BOURNS LABORATORIES

General Offices: 6135 Magnolia Avenue Riverside, California
Plants: Riverside, California—Ames, Iowa

VISIT OUR BOOTH #319 ISA SHOW

NEW PRODUCTS

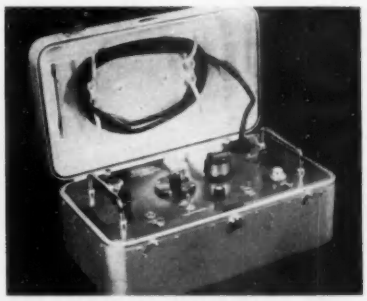
it would appear inside its helium-filled, hermetically-sealed case. The unit is built with an extremely light but very efficient motor, and comes with either AN connectors or the new pigmy type. It also features a choice of inductive or potentiometer pickoffs. Humphrey, Inc., San Diego, Calif.

Circle No. 24 on reply card

ACCELEROMETERS

A new line of accelerometers, designed for a wide range of constant or uniformly varying accelerations, is now in production. Variations of conformation, g-ranges, natural frequency, and damping will be developed to meet special requirements. Standard natural frequency varies from 5 to 30 cps for acceleration measurements of from 0-1 to 0-30 g's. The Viscous-damped units have an overall accuracy, including linearity, hysteresis, and repeatability, of within 1.5 percent.—Fairchild Controls Corp., Hicksville, N. Y.

Circle No. 25 on reply card



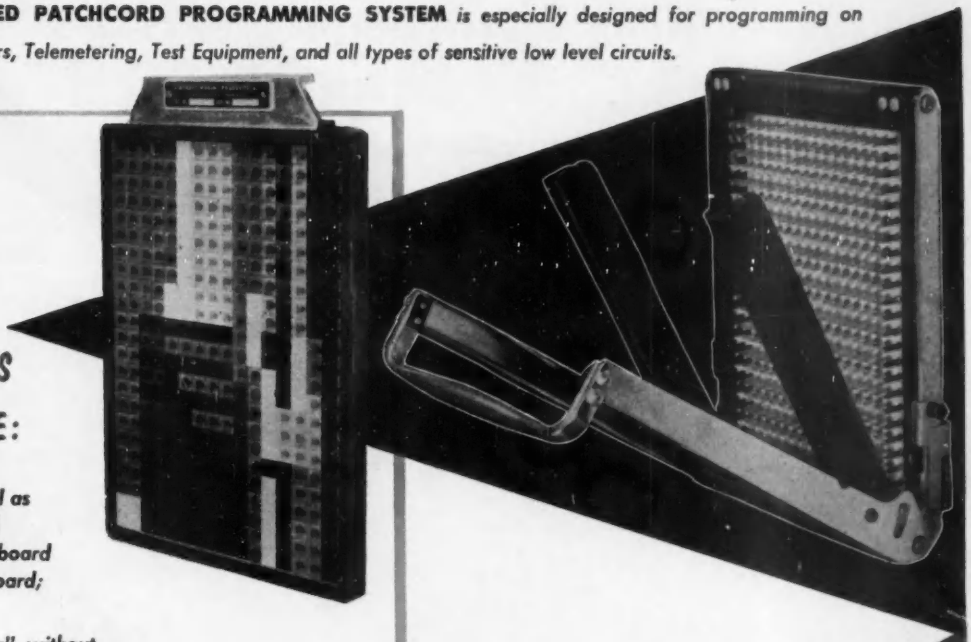
HAS DIGITAL READOUT

Model 9000 electronic weighing unit, designed for strain gage load cells of any bridge resistance, weighs just 22 lb and measures 16 by 8 by 9½ in. Manual balance with digital readout of four significant figures simplifies direct weighing. In control applications, relay closure occurs within 15 millisec after the applied load reaches the dial setting. When used with strain gage pressure transducers, the weigher becomes a rapid and highly accurate pressure switch. Ranges of from 1 to 10 millivolts per volt, full-scale, are common; resolution is about 0.4 microvolt per volt.—Hoover Electronics Co., Albuquerque, N. M.

Circle No. 26 on reply card

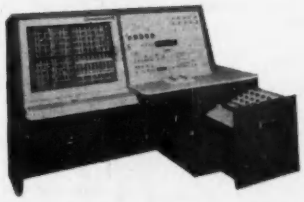
It's New! It's Revolutionary!

AMP's SHIELDED PATCHCORD PROGRAMMING SYSTEM *is especially designed for programming on Analog Computers, Telemetering, Test Equipment, and all types of sensitive low level circuits.*



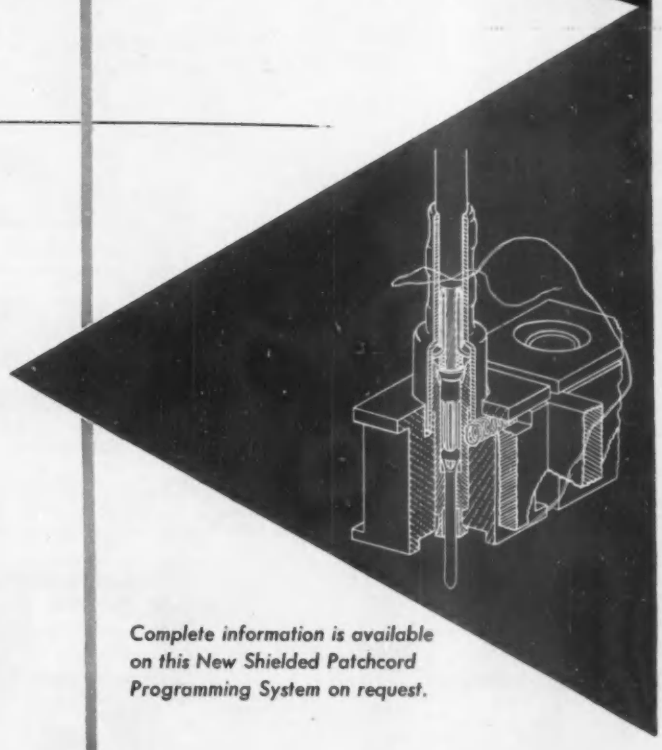
NEW DESIGN FEATURES INCLUDE:

- *Fully insulated as well as shielded removable frontboard and fixed rearboard;*
- *"Post Patching", without shorting as required in Analog Computers and Telemetering;*
- *Custom Color-Coded circuit legend provided by a cellular type construction that permits individual hole identification;*
- *Elimination of signal leakage between circuits;*
- *Shielded Patchcords, with shield terminated by a contact ferrule, which connects to ground when Patchcord tip is inserted.*



The illustration shows how Berkeley Division of Beckman Instruments, Inc., is using AMP's new Patchcord System in its new EASE* 1200 Analog Computer.

*Trade Mark, Berkeley Division of Beckman Instruments, Inc.



Complete information is available on this New Shielded Patchcord Programming System on request.

AMP

AMP INCORPORATED
3208 Eisenhower Boulevard
Harrisburg, Pennsylvania

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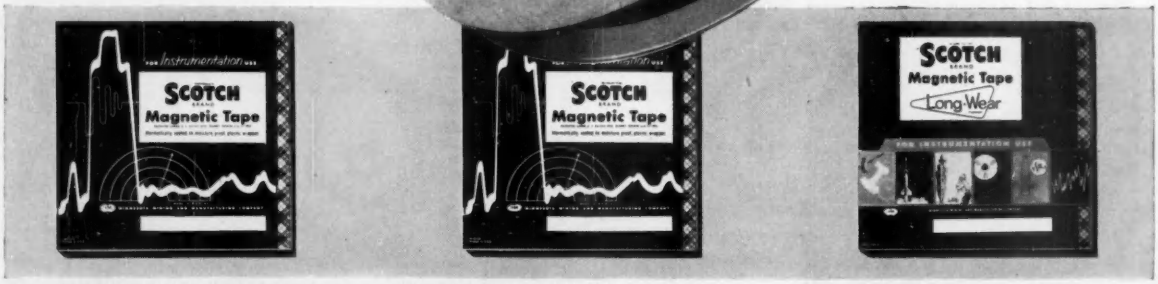
TAPES YOU CAN TRUST!



109—INTERNATIONAL STANDARD—For moderate speeds, tensions, pressures. 1.5 mil cellulose acetate backing. Uniformly accurate because of carefully milled resinous components, rigidly controlled oxide manufacturing process. .55 mil coating of standard output oxide.

106—GENERAL PURPOSE—Uses the same reddish-brown oxide as offered in No. 109 Instrumentation Tape. Because of its dimensional stability, this tape is recommended for multi-track applications. "Weather-balanced", it's ideal in extremes of temperature and humidity.

128 — HIGH OUTPUT — 100% more output (+6db) at 15 mil wave length. This tape is specifically designed for uses where high output at long wave length is required. 1.5 mil polyester base achieves high dimensional stability. .65 mil coating of "High Output" oxide.

159—EXTRA PLAY—50% more recording time on the reel! Made with 1 mil polyester backing, .35 mil coating of high potency oxide. Offers improved high frequency response, improved short wave length output, and better head conformity eliminates signal loss.

148—LONG WEAR—Rugged newcomer! This premium tape gives you 3.5 db greater output at short wave lengths, yet withstands heat-wear in temperatures up to 200°F. and eliminates head build-up. Has 1.5 mil polyester backing, .35 mil coating of "High Output" long wear oxide.

149—LONG WEAR, EXTRA PLAY—Matches 148 for heat-wear resistance and magnetic properties but records 50% longer because of its thinner 1 mil polyester backing. Selection for use of this tape should be based on strength versus playing time as the determining factor.

Choose from a complete line of "Scotch" Brand Instrumentation Tapes for industry and defense

Whatever your recording requirements, "SCOTCH" Brand has the right magnetic tape for you. Here's the world's fullest line of tapes for exacting instrumentation use — and the most reliable. Every "SCOTCH" Brand Instrumentation Tape meets critical dropout specifications. In pulse recording these tapes average less than 1 error per roll.* In direct recording, these tapes conform to proposed Navy specifications defining dropouts as variations of 22% or more in signal magnitude, lasting 300 or more microseconds.** All tapes shown are available in standard widths of ¼", ½", ⅝", ¾" and 1".

FREE BOOKLET gives you specific engineering data on dropouts plus complete physical and magnetic specifications of these famous "SCOTCH" Brand products. Write: Minnesota Mining and Mfg. Co., Dept. PJ-97, St. Paul 6, Minnesota.

*Measured by recording 200 non-return pulses per inch on a 0.035" track. A reduction to less than 50% normal signal amplitude constitutes a signal error. Zero errors are measured by saturating the tape undirectionally. Each spurious signal greater than 10% of normal signal amplitude constitutes a zero error. Errors per roll based on recording 7 tracks on rolls ½" x 2500'.
**Based on a 8750 cps signal played at 7.5 ips.

SCOTCH BRAND Magnetic Tapes

WHICH MAGNETIC TAPES ARE BEST FOR YOUR INSTRUMENTATION NEEDS?

Tape Number and Description	Stability	Strength	High Temperature Performance	High Speed Performance	Long Wave Length Output	Short Wave Length Output	Recording Time
108 General Purpose	Best	Best	Good	Good	Good	Good	Normal
109 General Purpose	Good	Good	Good	Good	Good	Good	Normal
128 High Output	Best	Best	Very Good	Very Good	Best	Good	Normal
148 Long Wear	Best	Best	Best	Best	Good	Best	Normal
149 Long Wear Extra Play	Best	Good	Best	Best	Good	Best	Extended
159 Extra Play	Best	Good	Good	Good	Good	Best	Extended

All quantities expressed are relative to No. 109

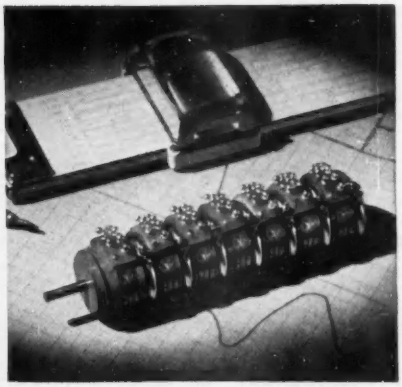
The term "SCOTCH" and the plaid design are registered trademarks for Magnetic Tape made in U.S.A. by MINNESOTA MINING AND MFG. CO., St. Paul 6, Minn. Export Sales Office: 99 Park Avenue, New York 16, New York. © 3M Co., 1957

Ace can meet your requirements in quality and delivery of NONLINEAR POTENTIOMETERS

Nonlinear precision wire-wound potentiometers in standard and subminiature sizes are now available in prototype or production quantities from Ace Electronics Associates . . *and you can be sure of delivery.*

These new Ace nonlinear units incorporate the same advanced engineering, precision craftsmanship, and controlled quality which have made ACEPOT linear potentiometers standards of excellence.

A new Division directed by highly qualified engineers, special prototype section, and mass production facilities are at your service to meet your requirements for quality and delivery of nonlinear precision potentiometers.



For complete information . . .

Call or write William Lyon or Abraham Osborn, Nonlinear Division, outlining your requirements. Your inquiry will receive prompt attention . . . and you will get delivery as specified.

Featuring!

Highly developed design techniques achieve high resolution and close conformity for your unique nonlinear requirements.

* Trademarks applied for

ACEPOT* ACETRIM*

ACE ELECTRONICS ASSOCIATES, INC.

Dept. C, 101 Dover St. • Somerville 44, Massachusetts

Telephone: SOmerset 6-5130 • *Engineering Representatives in Principal Cities*

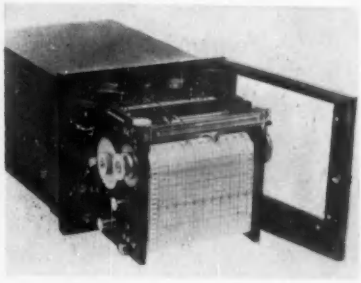
NEW PRODUCTS

INTERVAL METER

The CMC Model 251-A Time Interval Meter is designed for the precise measurement of elapsed time between two events occurring in the range of 3 microsec to 1 sec. Optional features permit extension of this range to 10 or 100,000 sec. Accuracy is within plus or minus 1 microsec. Typical applications include ballistics measurements, relay timing, testing of mechanical and electromechanical timing devices, etc. Two independent, continuously adjustable trigger level controls permit full rated sensitivity—0.2 volt rms—at any level between minus 300 and plus 300 volts.—Computer-Measurements Corp., North Hollywood, Calif.

Circle No. 27 on reply card

INFORMATION DISPLAY INSTRUMENTS

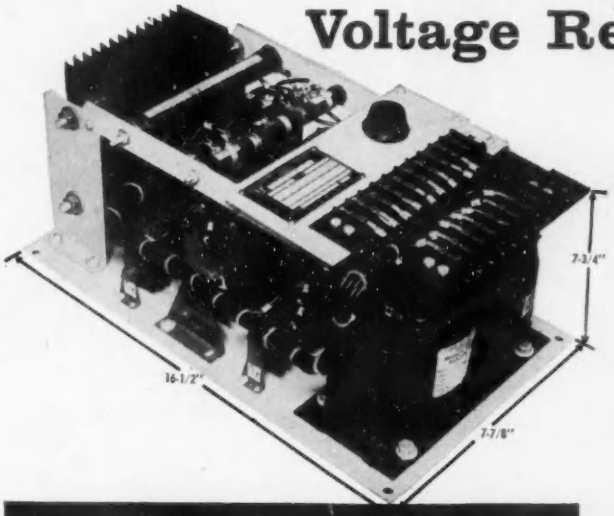


TWO-PEN MINIATURE

The two pens in this new recording potentiometer write margin to margin on a single 5-in. strip chart, producing two continuous records in a smaller space than is required by two 3-in. recorders. Amplifiers, are completely transistorized. The recorders are available with one front-set limit switch and three back-set switches on each pen. Accuracy is to within 0.5 percent on each pen and sensitivity is within 0.14 percent of scale span. Optional features: transmitting slidewires, quick change or manual change gears for three-speed chart drive, automatic reference junction compensation, table or panel mounting, and margin-marker pens. — Westronics, Inc., Fort Worth, Tex.

Circle No. 28 on reply card

Now! A Low-Priced Completely Static Voltage Regulator

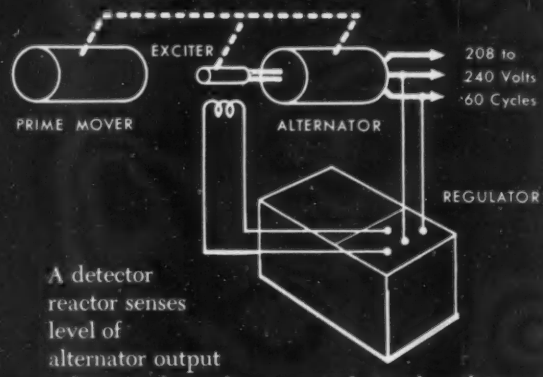


by

VICKERS*

For Fast, Accurate Voltage Regulation of 60-Cycle Alternators

How the Vickers Static Voltage Regulator Works



A detector reactor senses level of alternator output voltage and supplies a control signal to the magnetic amplifier stage. The amplifier in turn maintains alternator output voltage constant by supplying controlled excitation to the exciter. A regulator control knob permits adjustment of alternator voltage.

This new unit is ideal for applications where a simple and inexpensive but rugged voltage regulator is desired. The Vickers regulator is a single-stage magnetic amplifier unit utilizing selenium rectifiers and wire wound resistors. It is completely static, with no moving parts, and is thus not affected by vibration. Other features:

- Works into 20 to 100 ohm exciter field resistance without adjustment.
- Supplies exciter field current within a range of 0.15 to 1.35 amperes.
- Connects directly to 208 to 240 alternator without need of a potential transformer. Operates with alternators having any output voltage when used with a 500 VA potential transformer.
- Adjustable line drop or reactive current compensation provides zero droop at a given load when a Vickers accessory current transformer is used.
- Extremely simple to install, with only 6 terminal connections.

*Trade Mark

Write Today for Complete Information, Including New Brochure, on the Vickers Static Voltage Regulator.

VICKERS ELECTRIC DIVISION
VICKERS INCORPORATED a unit of Sperry Rand Corporation

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LEADERS IN ELECTRICAL CONTROL EQUIPMENT
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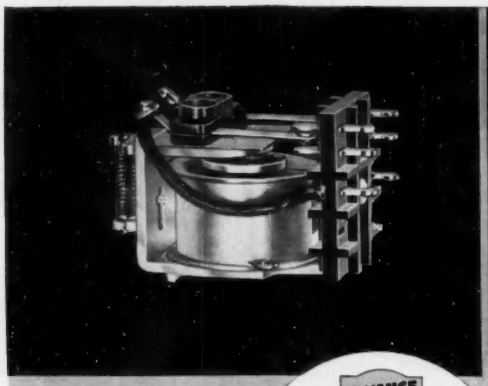
Selenium Rectifiers • Magnetic Particle Brakes and Clutches
Photoelectric Cells



ELGIN
announces the
NEW ADVANCE GH
SERIES
Low Cost
Midget Relays
. . . open or plastic enclosed

Elgin's new GH series combines the high efficiency required of general purpose relays with low cost. Their midget size suits them for installations where space is a problem (see specifications below). Open relays in 5 and 10 ampere ratings and clear plastic dust-tight enclosed 5 ampere relays are immediately available from stock. Specify dependable ELGIN performance . . . specify GH from your electronic parts distributor!

SPECIFICATIONS

NOMINAL POWER REQ.—DC relays, 1 to 2 watts; AC relays, 2 to 3 volt amperes.
NOMINAL VOLTAGE—DC relays, 6 to 120 volts; AC relays, 6 to 220 volts. (On specification, DC voltage coil up to 220 volts or AC voltage coil up to 440 volts can be supplied.)
RESISTANCE — DC relays, 25 to 8,000 ohms; AC relays, 4 to 5,000 ohms.
PULL-IN CURRENT VALUES—7.2 Milliamps max. at 2,500 ohms; 5.0 milliamps max. at 5,000 ohms.
DUTY CYCLE—continuous.
TEMPERATURE RANGE— −55° to +85°C when specified.
INSULATION RESISTANCE — 100 megohms min.
DIELECTRIC STRENGTH — standard: 500 volts RMS. (When specified, 1,000 volts RMS can be met.)
MAXIMUM WEIGHT—2 ounces.

GHA SERIES, 5 amp. open relay

Contact rating, 5 amps. resistive, 2 amps. inductive at 115 volts AC or 26.5 volts DC. Contact material is fine silver, 1C,2C,3C arrangements only. Relay is 1.1" high, 1.732" long and .937" wide. Contact terminals can be used as solder lugs or for printed circuitry.

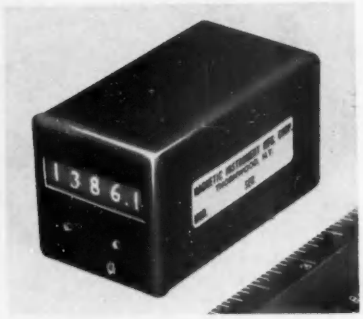
(Also available: GHB series, 10 amp. open relay.)

GHP SERIES, 5 amp. clear plastic enclosed relay.

Dust-tight plug-in. Contact rating, 5 amps. resistive, 2 amps. inductive at 115 volts AC or 26.5 volts DC. Contact material is fine silver, available in 1C or 2C arrangements only. Enclosure is $2\frac{11}{16}$" x $1\frac{13}{32}$" overall. $2\frac{1}{8}$" overall length above chassis.

ELECTRONICS DIVISION
ELGIN NATIONAL WATCH COMPANY
2435 N. Naomi Street, Burbank, California

NEW PRODUCTS



UNIQUE GEAR TRAIN

Pictured is a new elapsed time indicator for keeping an accurate record of actual "on" time in airborne or ground equipment. Typical applications include radar sets, computers, and navigational systems. Principle design features include a new type of low-speed synchronous motor and a unique gear train arrangement that provides a 14,400-to-1 ratio using only four gears. The indicator measures $1\frac{1}{4}$ in. sq by $2\frac{1}{4}$ in. long and weighs only 4 oz. Time range is 9,999.9 hours indicated on 5 counter wheels. Entire unit is hermetically sealed.—Magnetic Instruments Mfg Corp., Thornwood, N. Y.

Circle No. 29 on reply card

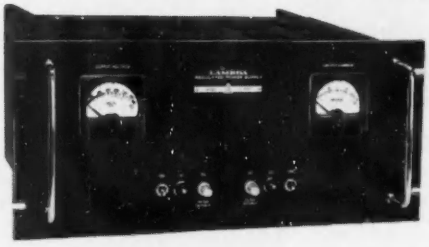
ADDS–SUBTRACTS

The Neuron, a new type of electromechanical counter, features a life of 300 million counts, count rates to 60 per sec, electric or manual reset, and excellent response to a variety of pulse shapes. The unit adds, subtracts, and totalizes. If add and subtract pulses are received simultaneously, a zero count results. No specific sequence of pulses is required and an incomplete pulse will not cause the counter to jam. Best results are obtained with a pulse on/off ratio of 1.0. While a square-wave pattern is desirable, other pulse shapes can be handled if their leading edges are reasonably

Three voltage ranges:
0-200, 125-325, 325-525 VDC

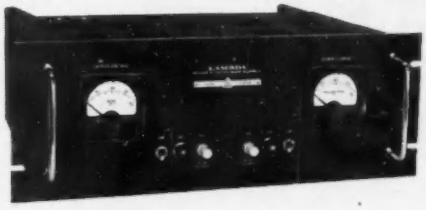
1.5 AMPERE MODELS NEED ONLY 8¾" OF PANEL HEIGHT!

(metered)		(unmetered)	
MODEL C-1580M:	0-200 VDC, 0-1500 MA....580.00	MODEL C-1580:	0-200 VDC, 0-1500 MA....550.00
MODEL C-1581M:	125-325 VDC, 0-1500 MA....605.00	MODEL C-1581:	125-325 VDC, 0-1500 MA....575.00
MODEL C-1582M:	325-525 VDC, 0-1500 MA....680.00	MODEL C-1582:	325-525 VDC, 0-1500 MA....650.00



800 MA MODELS NEED ONLY 7" OF PANEL HEIGHT!

(metered)		(unmetered)	
MODEL C-880M:	0-200 VDC, 0-800 MA....370.00	MODEL C-880:	0-200 VDC, 0-800 MA....340.00
MODEL C-881M:	125-325 VDC, 0-800 MA....345.00	MODEL C-881:	125-325 VDC, 0-800 MA....315.00
MODEL C-882M:	325-525 VDC, 0-800 MA....390.00	MODEL C-882:	325-525 VDC, 0-800 MA....360.00



400 MA MODELS NEED ONLY 5¼" OF PANEL HEIGHT!

(metered)		(unmetered)	
MODEL C-480M:	0-200 VDC, 0-400 MA....289.50	MODEL C-480:	0-200 VDC, 0-400 MA....259.50
MODEL C-481M:	125-325 VDC, 0-400 MA....274.50	MODEL C-481:	125-325 VDC, 0-400 MA....244.50
MODEL C-482M:	325-525 VDC, 0-400 MA....289.50	MODEL C-482:	325-525 VDC, 0-400 MA....259.50

200 MA MODELS NEED ONLY 5¼" OF PANEL HEIGHT!

(metered)		(unmetered)	
MODEL C-280M:	0-200 VDC, 0-200 MA....214.50	MODEL C-280:	0-200 VDC, 0-200 MA....184.50
MODEL C-281M:	125-325 VDC, 0-200 MA....189.50	MODEL C-281:	125-325 VDC, 0-200 MA....159.50
MODEL C-282M:	325-525 VDC, 0-200 MA....199.50	MODEL C-282:	325-525 VDC, 0-200 MA....169.50

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For all power supply needs through 1.5 amperes:

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Fills the need for compact, regulated DC power supplies. Economy of panel space, functional simplicity, new quick-service features.

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400 MA, 800 MA, and 1.5 ampere models include new, high-efficiency, long-life, hermetically-sealed semi-conductor rectifiers. All Com-Pak models are constructed with hermetically-sealed transformers, chokes and capacitors.

Condensed Data

LINE REGULATION . . . . . Better than 0.15% or 0.3 Volt, whichever is greater.

LOAD REGULATION . . . . . Better than 0.25% or 0.5 Volt, whichever is greater.

INTERNAL IMPEDANCE

C- 200 Series . . . . . Less than 6 ohms.
C- 400 Series . . . . . Less than 3 ohms.
C- 800 Series . . . . . Less than 1.5 ohms.
C-1500 Series . . . . . Less than 0.75 ohms.

RIPPLE AND NOISE . . . . . Less than 3 millivolts rms.

POLARITY . . . . . Either positive or negative may be grounded.

AMBIENT TEMPERATURE . . . Continuous duty at full load up to 50°C (122°F) ambient.

AC OUTPUT
(unregulated) . . . . . 6.5 VAC (at 115 VAC Input).

C- 200 Series . . . . . 10 AMP
C- 400 Series . . . . . 15 AMP
C- 800 Series . . . . . 20 AMP
C-1500 Series . . . . . 30 AMP

AC INPUT . . . . . 105-125 VAC, 50-400 CPS

OVERLOAD PROTECTION . . . AC and DC fuses; built-in blown-fuse indicators.

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MICRO-BEARING ABSTRACTS

by **A. N. DANIELS**, *President*
New Hampshire Ball Bearings, Inc.

BEARING FITS AND FITTING PRACTICES

As shown in *Fig. 1*, the fitting of Micro-Bearings, like the fitting of larger ball bearings, chiefly involves the clearances between the inside diameter of the housing and the outside diameter of the bearing; the bore of the bearing and the shaft diameter.

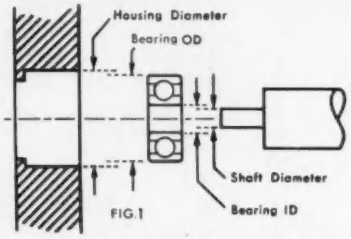

FIG.1

The achievement of the desired fit by dimensioning is illustrated in *Fig. 2*. The bearing ID is represented by the top blocks and the shaft OD is represented by the lower blocks. Such a block diagram could also be applied to housings and bearing outside diameters. In this block diagram, it will be noted, the bearing ID is represented by a .00015 tolerance with a similar tolerance for the shaft. A resulting fit of line to line to .0003 loose is shown.

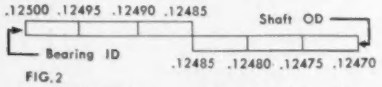

FIG.2

An interference fit not tighter than line to line is suggested for the following reasons:

1. *Difficulty in assembly.*
2. *Difficulty in disassembly. This is often more hazardous than the assembly operation and may result in total bearing destruction.*
3. *Reduction in radial play.*
4. *Danger of bearing ring conforming to possible poor geometry of mating shaft or housing.*

TOLERANCE DISTRIBUTION

The maximum .0003 loose condition shown in *Fig. 2* may be excessive in some applications. The fitting problem then resolves itself to reducing this extreme, and yet maintain the maximum tight fit of line to line. The looseness may be reduced by redimensioning the shaft to .12490/.12475 as shown in the block diagram, *Fig. 3.*

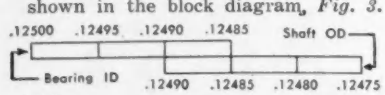

FIG.3

If the frequency distributions of shaft and bearing ID sizes were statistically normal, the modal fit of all parts would be 0.0001 loose. Accordingly, an insignificant percentage of parts would be mated to the extreme values, and for practical purposes could be ignored.

With regard to bearings' outside diameters and bores, however, normality of the distribution curve cannot be assumed. During the grinding operation, the "most metal tendency" tends to skew the frequency distributions for bearing ID's and OD's in the direction of most metal.

In grinding and finishing shafts and housings, similarly skewed distributions occur.

Operating on a modified probability distribution of tolerance is possible if the volume of parts is sizeable. But the approximate distribution of shaft and housing sizes must be verified if this method is to be used.

MATERIALS and SURFACE FINISHES

The ease of assembly is also affected by materials and finishes. The following factors must be considered:

1. *The galling characteristics, hardness and ductility of the materials involved.*
2. *Finish lay patterns produced by various tools and techniques used.*
3. *R M S surface finish values achieved.*
4. *Geometry of shafts and housings as regards out-of-roundness, taper, etc.*

The possible combinations of these elements in any single application are so numerous that their gross effect can only be ascertained by trial and error, or by a detailed study of operations on individual applications. A more complete discussion of fitting practices, including sizing methods and coding, is found in our design handbook.

DESIGNERS HANDBOOK FREE TO ENGINEERS

If you work with miniature bearings, you'll find this new, 70 page authoritative publication a great help in solving problems in designing instruments or small electro-mechanical assemblies.

It will be sent free to engineers, draftsmen and purchasing agents. Write to:

NEW HAMPSHIRE BALL BEARINGS, INC., PETERBOROUGH 1, NEW HAMPSHIRE

NEW PRODUCTS

steep. Prices, depending on the accessories required range from $143 to $293.—Autron Engineering, Los Angeles, Calif.

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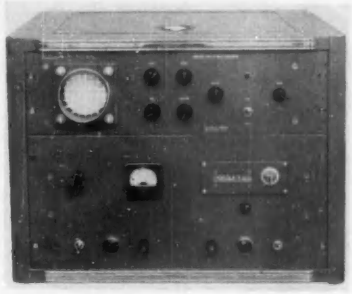


HOLE DETECTOR

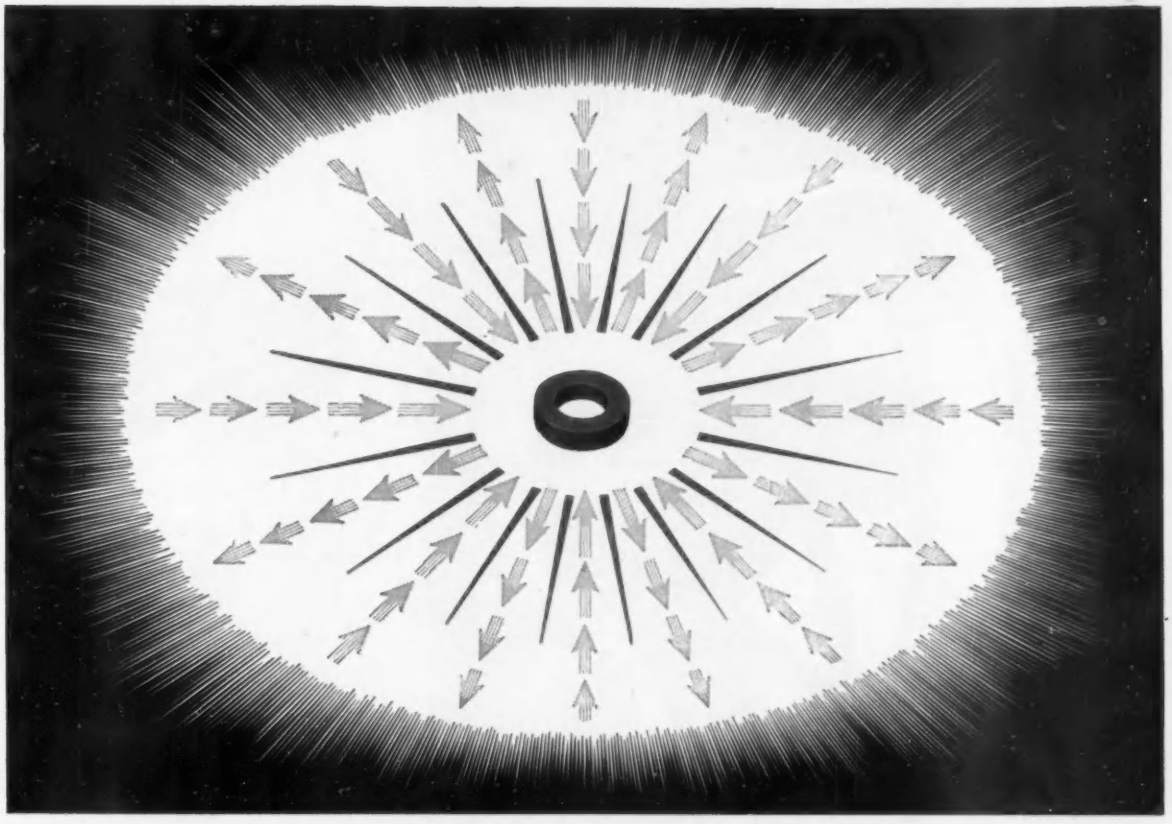
The Model KP-1 Pinhole Detector instantly spots and counts pinholes, however minute, in thin, electrically nonconductive films. As the film is drawn over an electrode, a high voltage (500 to 20,000 volts) sends a short-duration (less than 5 microsec) spark through any pinhole. The film is not damaged in any way; the spark merely registers on a built-in counter. An automatic disconnect cuts off the high voltage if a stoppage occurs in the film travel. The detector may also be used to actuate a remote audible signal.—Tinker & Rasor, San Gabriel, Calif.

Circle No. 31 on reply card

AIRBORNE OSCILLOGRAPH

The new Type 5-122 recording oscillograph was developed specifically for flight-test recording at high temperatures. The explosion-proof unit will operate in ambient temperatures of from minus 65 to plus 250 deg F, at altitudes up to 120,000 ft. Its crash-resistant magazine has a safety shutter that automatically closes when the

Transistorization of computers now a reality!



NEW...RCA 222M2 FERRITE MEMORY CORE

FASTER turnover time . . . HIGHER output signal . . . LOWER drive requirements

Faster turnover . . . higher output . . . all of this with an .080" O.D. core which operates with driving currents in the range of 300-500 milliamperes!

The RCA 222M2 is comparable to high drive cores in its ability to withstand large disturbing current pulses without reversing its flux state.

Write today for technical data and availability information on samples.

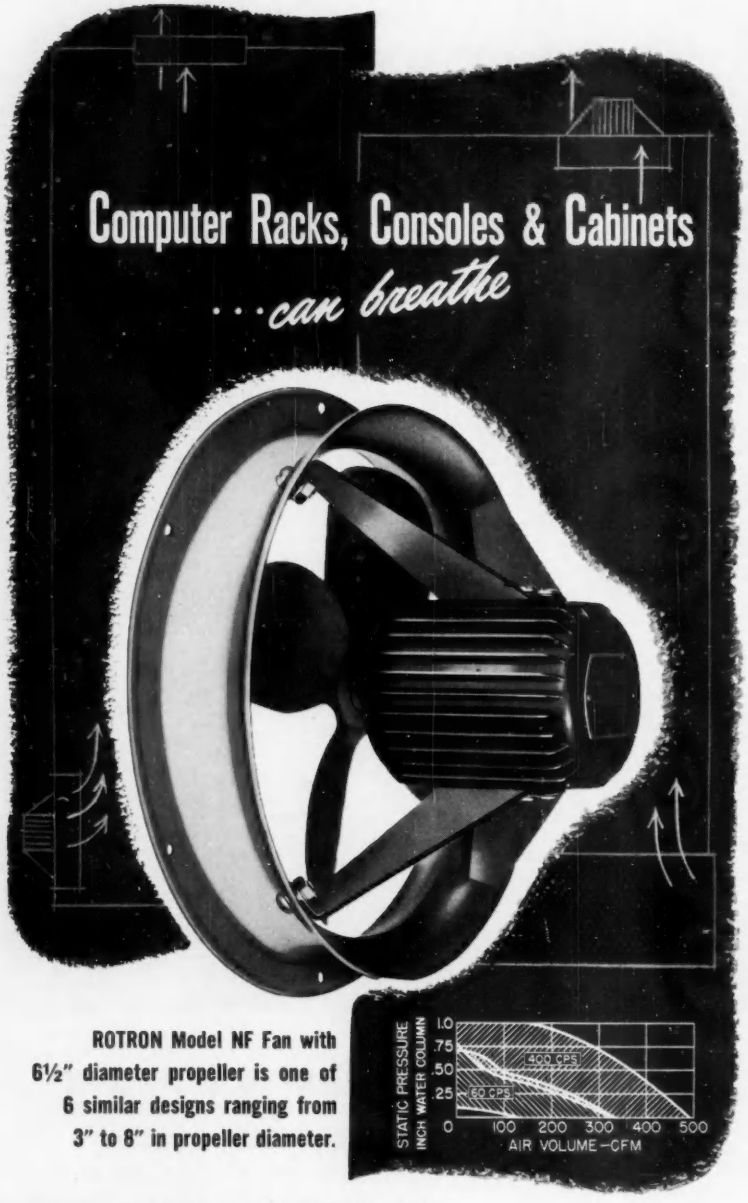
RCA TRANSFLUXORS . . . a developmental memory device utilizing a ferrite core with two apertures and exhibiting a nearly rectangular hysteresis loop. It can control the transmission of ac power according to a level established by a single setting pulse and furnishes an output determined by the stored pulse for *an indefinite length of time*. Once set, the TRANSFLUXOR does not require an input command to furnish output intelligence.

RADIO CORPORATION of AMERICA

COMPONENTS DIVISION — CAMDEN, N. J.

Computer Racks, Consoles & Cabinets

...can breathe



ROTRON Model NF Fan with 6½" diameter propeller is one of 6 similar designs ranging from 3" to 8" in propeller diameter.

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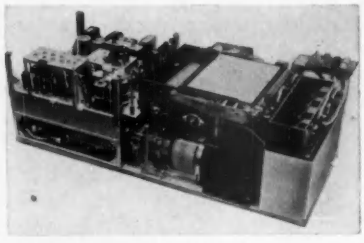
CATALOG SHEETS: 50105-1 & 50105-2

ROTRON MANUFACTURING CO., INC.

WOODSTOCK • NEW YORK

magazine is removed. Up to 26 channels can be recorded at writing speeds above 12,000 ips. Twelve discrete record speeds give a range of 0.047 to 96 ips, and a jump-speed system allows the operator to pre-select speed ratios of 8:1, 4:1, or 2:1.—Consolidated Electrodynamics Corp., Pasadena, Calif.

Circle No. 32 on reply card



RADAR RECORDER

This new automatic device presents a photograph of the ground beneath the plane as seen by an airborne radar system. This means navigation to pinpoint accuracy. The photograph of radar information is printed on a 9½ in.-wide, slowly moving film strip that pictures the ground immediately aft of the plane exactly as it looked to high-precision radar 20 sec before. Synchronizing film speed with the speed of the plane results in a permanent record of the flight path.—Hycon Mfg. Co., Pasadena, Calif.

Circle No. 33 on reply card

VERSATILE INDICATOR

This new digital flow indicator and totalizer gives a direct reading in rpm and in gallons per minute or hour, and can be adjusted to specific gravity changes to give readings in pounds per minute or hour. When used with two Pottermeters, it will indicate the ratio between two flows. It samples desired information for a controlled period adjustable from 1/10 millisec to 10 sec in increments of 1/10 millisec. The

THE ONE UNIVERSAL METER

MICROVOLTS TO KILOVOLT

The **KIN TEL** Model **203** is a combination DC microvolt-ammeter and amplifier. It provides an exceptionally wide range of measurements. Fifteen voltage ranges cover from 100 microvolts full scale to 1000 volts full scale, with 100 megohms input impedance. Ten current ranges cover from 100 micro-microamperes full scale to 100 milliamperes full scale. As little as 10 microvolts or 10 micro-microamperes may be measured with accuracy. The uncluttered zero-center meter face instantly indicates polarity on a mirrored scale. When used as a DC amplifier, the instrument features exceptionally low drift with high gain, very high input impedance and low output impedance. Gains up to 80 db with less than 10 microvolts drift may be obtained. The Model **203** utilizes **KIN TEL'S** unique chopper stabilized circuit to provide high sensitivity with previously unobtainable drift-free stability and high input impedance.

APPLICATIONS: Electronic, medical, geophysical, chemical, metallurgical research and development . . . transistor production and circuit design . . . thermocouple calibration . . . null detector . . . recorder driver amplifier . . . and as a general purpose laboratory instrument wherever dc voltage and currents are measured or amplified.

SPECIFICATIONS

Voltage Range (full scale)	100μv to 1000v
Current Range (full scale)	100μμa to 100 ma
Input Impedance	10 megohms below 10 mv, 30 megohms at 30mv, 100 megohms above 30mv
Impedance Accuracy	±1.5%
Accuracy on All Ranges	±3% of full scale
Maximum Gain as Amplifier	80 db ±1.5%
Output Rating	1v across 1000Ω
Output Impedance	less than 5Ω
Drift (after 15 min. warmup)	10μv equivalent input
Price	$550.00

Rack Mounting available as Model 203R

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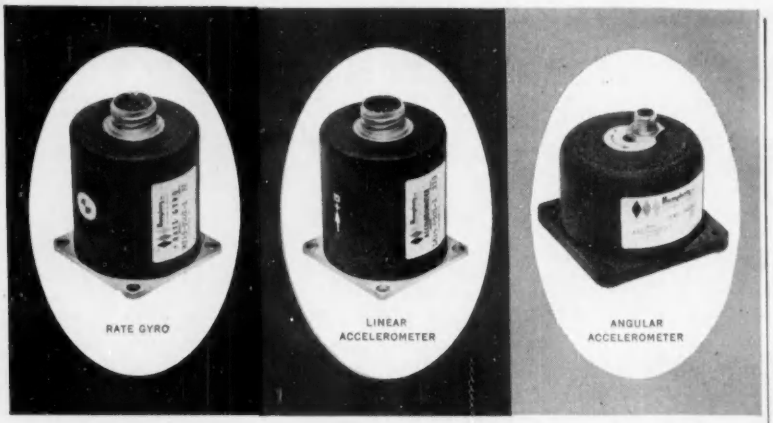


Advanced Instrumentation by Humphrey

New production inertial sensing instruments for extra precision and reliability

Among the outstanding features of Humphrey's new inertial sensing instruments are: dry helium filled, hermetically sealed steel cases; standardized mountings for rate gyro and linear accelerometer; and choice of regular AN connector or new pigmy connector.

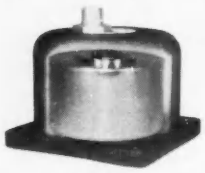
RATE GYRO is of new simplified design, with light-weight efficient motor, accurate trouble-free damping, and choice of inductive or potentiometer pick-off.

LINEAR ACCELEROMETER is of dual contra-rotating mass design. It has practically zero sensitivity to cross acceleration and angular acceleration; ± symmetrical or asymmetrical ranges (0 to 1G) to (0 to 100G).

ANGULAR ACCELEROMETER is compactly designed with completely symmetrical inertial ring. Available ranges are from zero to ± ½ rad/sec² to zero to 100 rad/sec.² Except in very low range, either potentiometer or inductive pick-off can be furnished. Performance for either instrumentation or control systems is excellent.

Rate Gyro—Model RG15-0102-1: New simplified design with light-weight efficient motor.

Linear Accelerometer—Model LA15-0501-1: Zero sensitivity to cross and angular acceleration.



Angular Accelerometer—Model AA01-0207-1: Excellent performance for instrumentation or control systems.

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instrument is suitable for a variety of applications but is best used as a short-time totalizer. The four-digit readout uses Burroughs Nixie tubes with their ¾-in. high numbers.—Potter Aeronautical Corp., Union, N. J.

Circle No. 34 on reply card

PORTABLE RECORDER

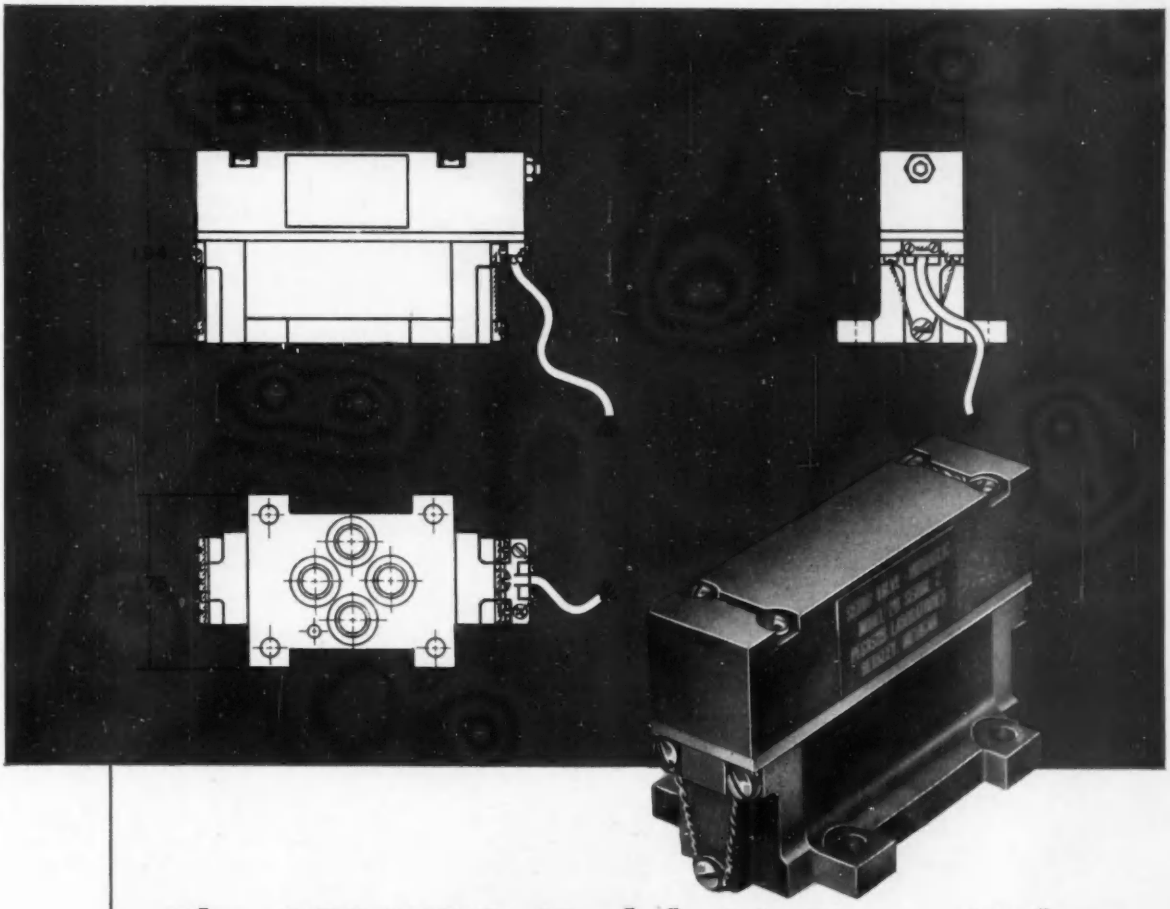
The Model 200 Recorder, a transistorized, dual-pen, strip-chart instrument of the servo-driven, self-balancing potentiometer type, features an unusual degree of reliability, fast response, high (10-mv) sensitivity, and good linearity. Dimensions are 10 by 10 by 15 in.; weight is 23 lb. Chart drive may be from an external shaft, a Selsyn, or a synchronous motor. Change gears provide for six chart speeds.—Mount Sopris Instrument Corp., Boulder, Col.

Circle No. 35 on reply card

COMPACT INDICATOR

Just 2 in. in diameter, a new self-contained, transistorized Engine Exhaust Temperature Indicator continuously displays temperature over a 200-to-1,000-deg-C range and has an accuracy within plus or minus 5 deg C. It has less than ⅓ the weight and volume of a comparable vacuum-tube unit, an instantaneous warm-up time, and a 2-sec full-scale response. The latter makes it highly suitable for multiple thermocouple installations. It can also be used as a monitoring unit with any number of chromel-alumel thermocouples and a suitable switching device.—Ford Instrument Co., Long Island City, N. Y.

Circle No. 36 on reply card



The PEGASUS Model 20 Servo Valve for Missile and Aircraft Application

IN THE MODEL 20, Pegasus presents a servo valve incorporating the highly reliable, high performance boost technique used in its line of industrial valves, yet meeting the particular requirements of low size and weight, low input power, and high temperature operating range of the aircraft industry.

THE UNIT incorporates high pressure strain barriers to isolate the electrical and magnetic areas of the valve from the hydraulic oil, and uses stainless steel throughout in its construction. The balanced boost drive provides full spool differential pressure for as low as one tenth of the maximum differential current, insuring maximum sensitivity and minimum balance shifts.

WE WOULD BE PLEASED to submit more information, quotations to your specifications, or prototypes of this unit upon your request.

SPECIFICATIONS

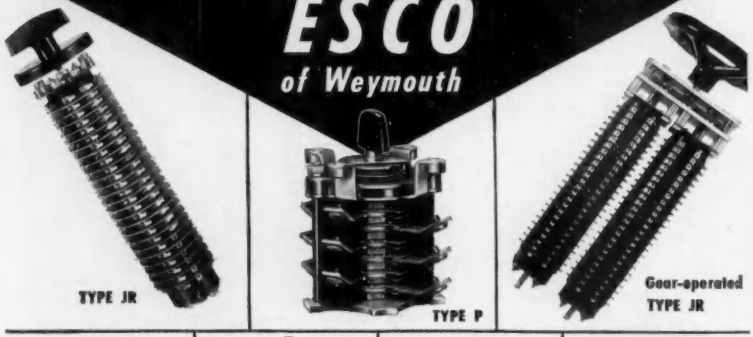
Weight	.95 pounds
Differential Current	± 8 m.a.
Coil Resistance	1500 ohms
Coil Inductance	2 henries
Flow Rating	20 in. 3 sec.
Null Leakage	.4 in. 3 sec.
Operating Pressure	500 to 3000 p.s.i.
Operating Temperature	−65 to 450°F.

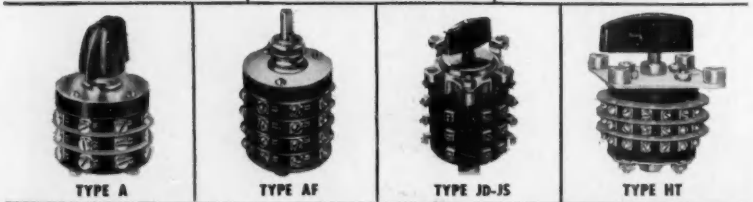
PEGASUS LABORATORIES, INC.

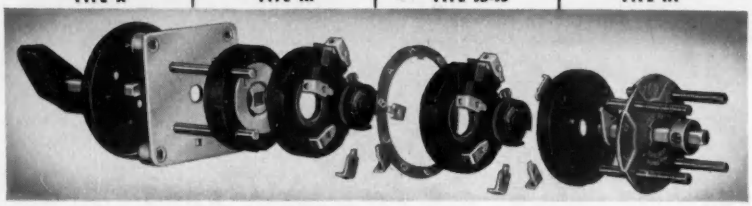
DESIGNERS AND MANUFACTURERS OF ELECTRO-HYDRAULIC SERVOMECHANISMS

3690 W. ELEVEN MILE ROAD • BERKLEY, MICHIGAN

SPECIAL SWITCHES are STANDARD with ESCO of Weymouth







When you need a SPECIAL switch . . .

ESCO standard, uniform components can be assembled to meet your requirements; or a deviation from one of our standard types will give you a special switch at a standard switch cost. *Over 90% of our production is SPECIAL in one way or another.*

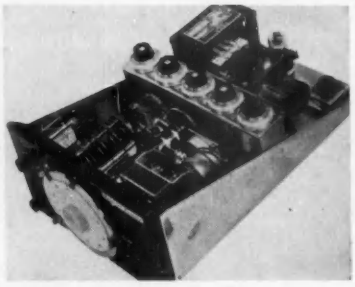
These standard switches can be modified to fit your application:

- **TYPE A** — up to 8 positions, 7 sections maximum, detent-mechanism, rating 5 amperes — 125 volts a-c/30 volts d-c.
- **TYPE AF** — up to 8 positions, 6 sections maximum, detent-action, rating with resistive load 5 amperes at 28 volts d-c or 115 volts 400 cps, per MIL-S-6807.
- **TYPE P** — Multi-section, up to 4 positions, snap-action, rating 10 amperes — 125 volts a-c, 5 amperes — 125 volts d-c, 30, 60, 100, 200 amperes at 500 volts a-c, or 250 volts d-c. Can be assembled to meet Specification MIL-S-15291.
- **TYPE JR** — up to 8 positions, 30 sections maximum, detent-action, rating 10 amperes at 125 volts a-c, 5 amperes 125 volts d-c.
- **TYPE JD-JS** — up to 8 positions, 5 sections maximum, detent-action or snap-action, rating 30 amperes at 230 volts a-c.
- **TYPE HT** — up to 16 positions, 6 sections maximum, detent-action, rating 5 amperes at 125 volts a-c.
- Bureau of Ships No. 9000-S6202-74085 rating 10 amperes at 120 volts a-c. BuShips 9000-S6202-74090, 9000-S6202-74096, and 9000-S6202-74224, ratings 30, 60, and 200 amperes, 500 volts a-c — 250 volts d-c.

Write for data sheets or catalog on ESCO rotary multipole switches — or send us your requirements and we'll give you full specifications on the ESCO switch that meets YOUR need.

ESCO of WEYMOUTH
ELECTRO SWITCH CORPORATION
Weymouth 88, Massachusetts

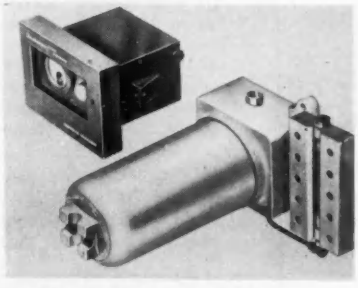
ANALYSIS INSTRUMENTATION



ACCURATE SAMPLES

This is the programmer, one of the units in the new Model 184 Process Vapor Fractometer. It is customarily installed with a recorder in a control room, and calibrates a third unit, the analyzer, which is installed in the plant close to the sample take-off point. One unusual design feature of the analyzer is a Teflon dryseal sampling valve, which accurately meters the sample volume and avoids adsorption effects of lubricants. The programmer occupies 7 by 11 in. of panel space. Recording is done on a bar chart.—Perkin-Elmer Corp., Norwalk, Conn.

Circle No. 37 on reply card



CORROSION CONTROL

A new explosion-proof Electrolytic Hygrometer is now available for controlling corrosion, product purity, and process efficiency. In the analysis, all moisture in a gas stream is electrolized by means of a special element, the amount of current thus required indicating the precise amount of moisture present. The unit automatically and continuously measures moisture

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Control Engineering — September, 1957

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Pass this card along to a friend or business associate

How to cope with an avalanche of urgent data

Tape keeps ballistic missile tests in manageable form

Four of the twenty-four Ampex FR-100 Tape Transports at the General Electric Missile and Ordnance Systems Department facility in Philadelphia.

Nobody intends to get buried, drowned, suffocated or trampled as the floodgates open on one of the biggest of all data-acquisition programs. For its ballistic missile development contracts, General Electric's Missile and Ordnance Systems Department has installed a data-processing and computation center to match the challenge.

A PREFERENCE FOR TAPE

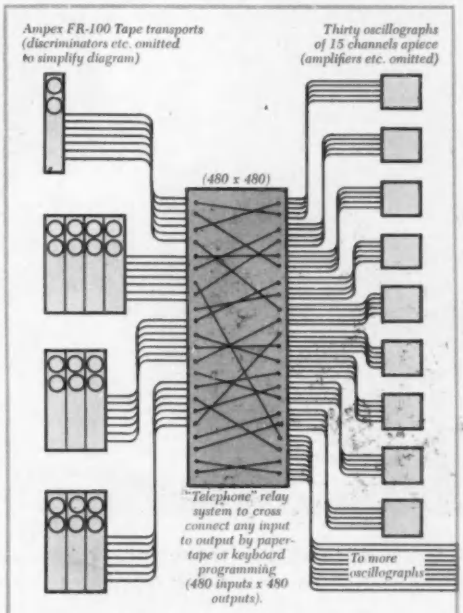
Of the test information received, about 90 percent will be on tape. Two facts about magnetic tape recording help keep the sheer mass of information under control: (1) hundreds of simultaneous parameters are recorded on one tape with a common time base; (2) tape gives live electrical voltages, hence reducing, correlating, computing and handling steps can be done automatically. General Electric's goal is to provide all interested engineering groups with both analog and computed data within three days of receipt of raw tapes.

Tapes from flight test, ground test and component development will be received from sources all over the U.S. These tapes will include quarter, half and one-inch widths. Hence most "tape stations" in the data-reduction system will have three Ampex FR-100 tape transports for the three widths. They will share electronics.

NOVEL USE OF A TELEPHONE TECHNIQUE

The right data must get to each of a large number of research and design groups. No traffic snarls allowed – so General Electric's engineers have made ingenious use of taped data's electrical form. They use a "telephone central station." After the necessary conversion steps, hundreds of channels of data from magnetic tape are fed into an automatic relay switching system. This connects them into 450 channels of oscillographic writeout (30 oscillographs with 15 channels apiece). When desired one input can go through a multiple relay putting the same data trace on two or more of the oscillograph records. Programming is done by a carefully checked paper tape. The end result is visual traces in a desired side-by-side relation. And each oscillograph record contains the data of interest to particular engineering groups.

Magnetic tape comes to life again in computation. The visual records are marked wherever special computer effort is required. Another group of Ampex FR-100 Tape Reproducers plays the tapes through a high-speed analog-to-digital conversion system which finds and converts selected sections to digital form at a rate of 45,000 conversions per second.


Ampex FR-100 Tape transports (discriminators etc. omitted to simplify diagram)
Thirty oscillographs of 15 channels apiece (amplifiers etc. omitted)
(480 x 480)
"Telephone" relay system to cross connect any input to output by paper-tape or keyboard programming (480 inputs x 480 outputs).
To more oscillographs

"Telephone" relay switching system from magnetic-tape data to oscillographic writeout.

If mass of data is your problem, we would be pleased to discuss some practical answers. Or would you like to have this informative ad series mailed direct? For either request, write Dept. HH-7.

MAGNETIC TAPE APPLICATIONS BY AMPEX

ONE OF A SERIES 7

Series FR-100

Series 800 Mobile and Airborne

Model FR-200 Digital

Series FL-100 Loop Recorders

Series FR-1100

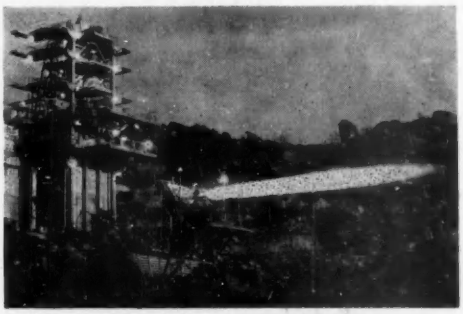
INSTRUMENTATION DIVISION AMPEX CORPORATION

FIRST IN MAGNETIC TAPE INSTRUMENTATION

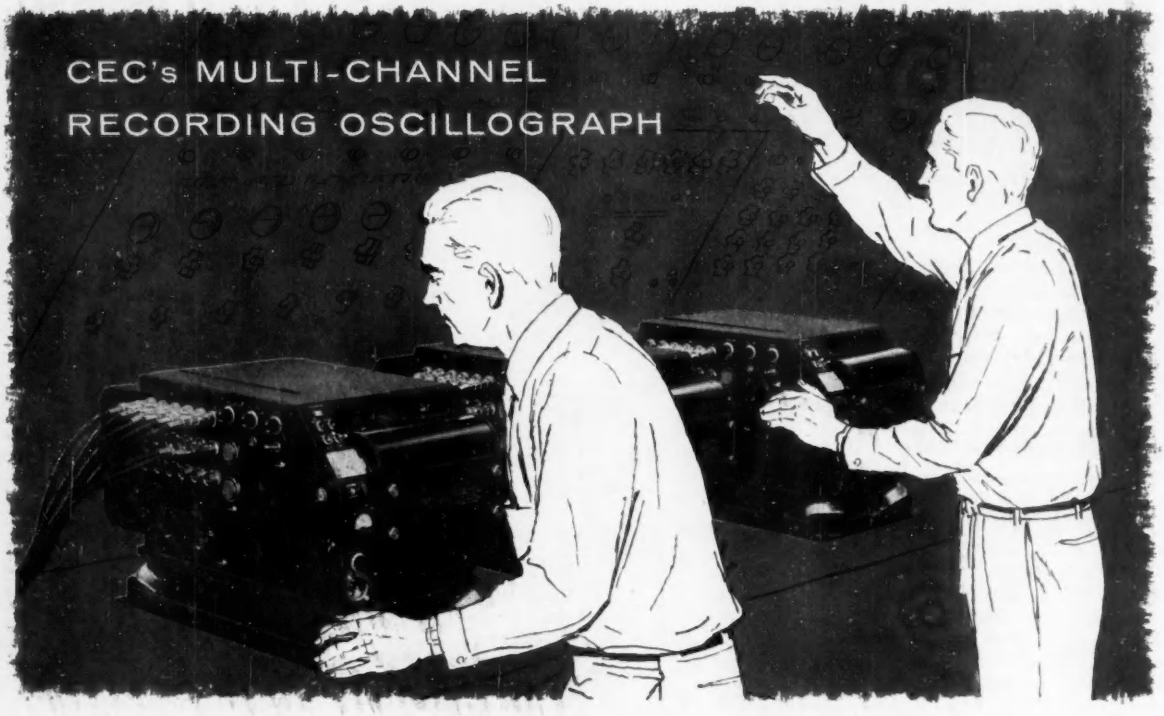
934 CHARTER STREET · REDWOOD CITY, CALIFORNIA

District offices serving all areas of the United States and Canada; Foreign Representatives in countries around the world.

Here's the reliable oscillograph that records rocket history



Rocketdyne, a division of North American Aviation, Inc.



At propulsion field laboratories, CEC's 5-114 Recording Oscillographs record such vital rocket engine parameters as temperature, pressure, flow, acceleration, and thrust over a broad range.

Noted for extreme accuracy

There is no tolerance for inaccuracy at rocket test stations. The most dependable, thoroughly proven data-recording instruments in the world are chosen to record data from rocket tests lasting only a few seconds. In this short time CEC's 5-114 Oscillograph simultaneously records as many as 18 or 26 distinct parameters with extreme clarity.

In the 5-114, a broad range of galvanometers offers response up to 5000 cps. Change gears provide an accurate 28-step range of speeds from .45″ to 115″/second with choice of 7″-wide record capacities up to 900 feet. Automatic record-length control, scanning system, record numbering, trace identifier, and shockmount base are standard features.

For complete information, contact your nearby CEC field office, or write for Bulletin CEC 1500-X16.

Consolidated Electrodynamics

300 North Sierra Madre Villa, Pasadena, California

OFFICES IN PRINCIPAL CITIES THROUGHOUT THE WORLD

concentrations in vapor samples with at least 95 percent accuracy in a 0-to-1,000-ppm range at temperatures up to 100 deg C.–Beckman Instruments, Inc., Fullerton, Calif.

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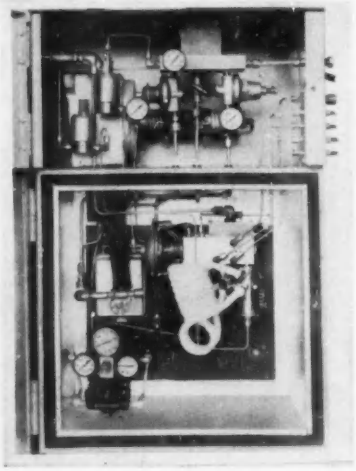


4-COMPONENT ANALYSIS

Shown is the Model 120-A industrial gas chromatograph control unit and analyzer section designed for the continuous analysis of up to four components of a specific gas stream. The two parts of the low-cost instrument can be separated by 1,500 ft and still maintain their measuring and recording accuracy. Other features are simplified control, visual and permanent recorder readout, an accuracy of plus or minus 1 percent, a locking door, an integrated test circuit to facilitate maintenance, and automatic or manual operation. Only the analyzer unit is shown here, cover removed.–Beckman Instruments, Inc., Fullerton, Calif.

Circle No. 39 on reply card

VERSATILE ANALYZER

The Davis Electro-Conductivity Analyzer has been designed for the continuous monitoring of parts per million content, in air, of any gas or vapor that will ionize in water (or whose combustion products will ionize in water). It is suitable for toxic gas control in work areas, for tracing impurity in process control (e.g., analyzing for residual hydrogen sulfide or mercaptans in natural gas) or for monitoring air for ppm of chlorine, nitrous fumes, phosgene, hydrogen sulfide, etc.–Davis Emergency Equipment Co., Newark 4, N. J.

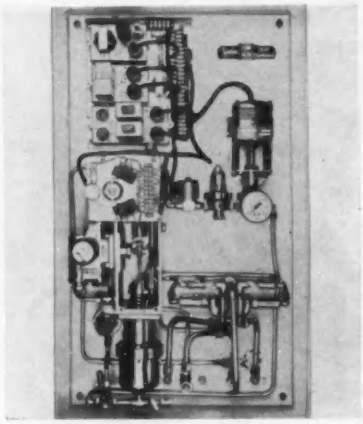
Circle No. 40 on reply card

PPM OXYGEN ANALYZER

The Series 11-400 Oxygen Analyzer continuously monitors oxygen content in process plant gas streams by measuring the electrochemical change in an oxygen-sensitive reagent exposed to a gas sample containing oxygen. A regenerator in the flow arrangement reduces the oxidized liquid, and permits a closed-loop operating cycle. Full-range sensitivity can be had for any oxygen value between 50 and 2,000 ppm. Units are available for recording, controlling, indicating, or telemetering to remotely located receivers.–Davis Instruments, Newark, N. J.

Circle No. 41 on reply card

CONTROL DEVICES



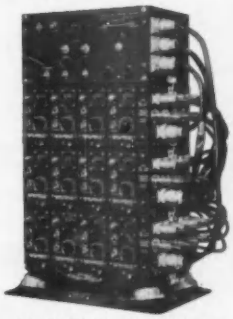
PACKAGED CONTROL

Shown is the control unit for the new Sparton/Cash Standard Type 300 Packaged Control System, designed for the remote positioning of valves, throttles, rheostats, and other final control elements. Pressure, flow, level, speed, and many other process variables can be controlled from a few feet to many miles away by a single operator at one central location. Fields of application would include municiple water distribution, sewage treatment, petroleum and chemical processing, and atomic energy operations. The single-package system combines the response speed of electronics with the smoothness of pneumatics and hydraulics, and uses a power supply, positioner, reducing valves, and booster

Ideal companions

for your CEC Recording Oscillograph

These extremely reliable units are teamed with CEC's Recording Oscillographs in the nation's leading rocket test centers.



CEC's AMPLIFIER SYSTEM D—Provides amplification, gain control, balance networks, and impedance-matching circuits to assist in recording output signals from self-generating or externally excited pick-ups. Offers any combination of linear/integrating amplifiers and carrier amplifiers up to 12 channels. Write for Bulletin CEC 1403-X6.

CEC's NEW MODULATOR—Now you can feed d-c signals from thermocouples or strain gages through the *carrier* amplifiers of System D. The new Catalog 15-005 Modulator produces full-scale amplifier output from a one millivolt d-c input. It is essentially a two-transistor electronic switch which converts low-level, static and quasi-static d-c signals into pulses acceptable for amplification by the carrier amplifier of System D. The 15-005 may be plugged directly into the amplifier case or into the amplifier input line with standard connectors.

Contact your nearby CEC field office, or write for the Bulletin mentioned above.

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Pasadena, California

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TELEMETRY

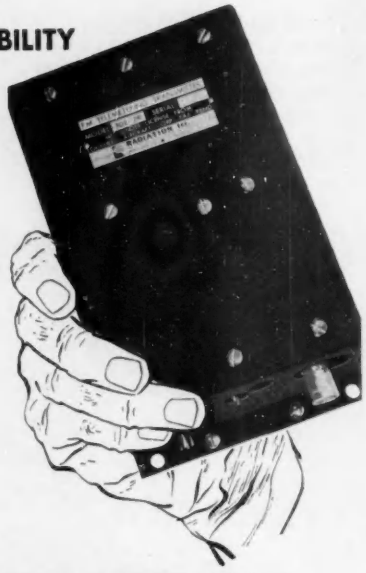
FM TRANSMITTER

MODEL 3115

- SMALL SIZE
- HIGH STABILITY

New, improved model designed for extreme environmental conditions (100g shock; 2000 cps vibration,—55 to +75°C). Subminiaturized and crystal-stabilized with telemetry band spurious output better than 60db below carrier.

Frequency Range: 215-235 mc
Frequency Stability: 0.01%
Power Output: 2 watts
Weight: 1.7 pounds



RF POWER AMPLIFIER

MODEL 3052

- RUGGED
- COMPACT
- RELIABLE

Provides 50 watts output from 2 watts input. Rugged construction and the use of a stacked ceramic tube makes this amplifier stable and reliable over a wide range of environmental conditions:

Temperature:	*—55° to +75°C*
Shock:	*100g*
Vibration:	*20g, 20-2000 cps*
Altitude:	*0-70,000 feet*

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NEW PRODUCTS

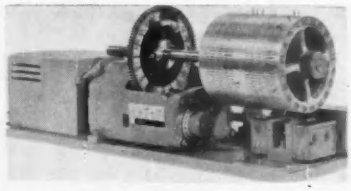
valve as standard components. Signal transmission is via telegraph, telephone, or private wires, and can also be handled by microwaves.—A. W. Cash Co., Decatur, Ill.

Circle No. 42 on reply card

SEALED RELAY

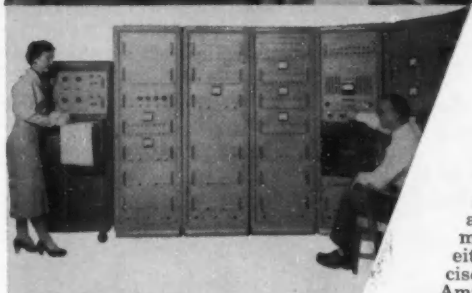
Designed for multiple generator systems and for high-speed, high-altitude aircraft, this new over-voltage relay will withstand frequency vibrations in the order of 10 g's to 500 cps. Features include a complete hermetic seal, a more rigid mounting bracket with interchangeable mounting dimensions, and a selector winding to detect the generator that has gone over-voltage. It meets AF spec MIL-R-25078A.—Hartman Electrical Mfg. Co., Mansfield, O.

Circle No. 43 on reply card



PROGRAM TIMER

An adjustable program timer for continuous, multistage circuit control is provided with a constant-speed drive actuated by a synchronous motor. This arrangement permits programming and recycling of complex switching patterns with respect to any time cycle up to a maximum of 4,000 sec. Range



for
analog computer
readout:

modern, compact, mobile

SANBORN

CONSOLE RECORDING SYSTEMS

Up to eight problem variables can be recorded in inkless, permanent, rectangular-coordinate tracings—with Sanborn's improved six- and eight-channel 156-, 158-5490 Console Systems. Less than four feet high and about two feet in width and depth, these Systems are completely mobile and designed for maximum operating convenience. Controls and indicators on the sloping top panel include individual-channel attenuation, position, balance, sensitivity and stylus heat adjustments; switch for turning off B + of output amplifiers; chart drive motor switch (can also be remotely controlled); code marker and/or one-second interval timer stylus switch. The Recorder unit, either six or eight channels, features paper loading from the top, and nine precisely controlled speeds from 0.25 to 100 mm/sec. Four dual-channel DC Driver Amplifiers of current feedback design are housed below the Recorder, and are mounted on a chassis which may be withdrawn for inspection.

Electrical specifications of the Console Recording Systems include a basic sensitivity of either .01 volt/chart division (5490 types) or 0.1 volt/chart division (5495 types); linearity of 1%; drift less than 1/2 chart division/hour (5490), less than 1/20 chart division/hour (5495); flat frequency response to 20 cps, down 3 db at 60 cps for all amplitudes to 5 cm peak; either single-ended or push-pull input signals of 5 meg. impedance (each input lead to ground).

A useful companion instrument is the new Sanborn Model 183 Programmer, designed to provide a connecting link between an analog computer and the Console Recording System. Shown mounted at the top rear of the Console, the Programmer operates the Console in the following automatic sequence: turns recorder drive on—feeds calibration signals to all channels—reads initial DC levels of computer—closes contacts to start computer problem—records computer output for a preset chart length—turns off recorder drive and resets itself for another cycle.

Further technical data, prices and delivery information — on the 5490/5495 Console Recording Systems and two- to eight-channel 5475/5480 Systems are available on request from your Sanborn Sales-Engineering Representative or the Industrial Division in Waltham.

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SANBORN COMPANY

INDUSTRIAL DIVISION

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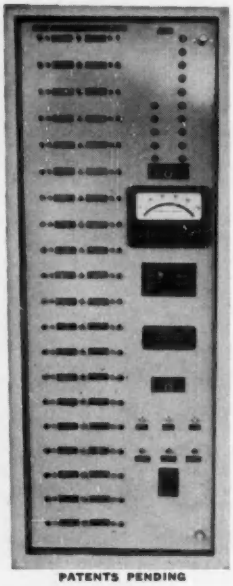


PATENTS PENDING

KYBERNETES PRESENTS ANOTHER COMPLETELY NEW CONCEPT IN INSTRUMENTATION

T

M

TEMPERATURE INDICATOR MONITOR FOR MONITORING 40 TO 80 THERMOCOUPLES

- WITH POTENTIOMETRIC ACCURACY
- INCORPORATING A BUILT-IN T. I. (TEMPERATURE INDICATOR)
- COMPLETELY ELECTRONIC WITH NO MOVING PARTS
- ALL IN ONE COMPACT INSTRUMENT*

TIM has been made possible through the incorporation of advanced techniques developed for The Kybernetes Data Logger. The three major components involved are the all-electronic potentiometric type amplifier with ground isolated input and high noise rejection factor, the alarm comparator, and the chopper stabilized power supply. These units have maximum long term drifts of .06%, .01% and .01% respectively.

FEATURES OF THIS INSTRUMENT INCLUDE —

- Non-interruption of alarm monitoring during readout on the T.I.
- Continuous alarm scanning at the rate of 5 points per second.
- Individual hermetically sealed plug-in relays for scanning to provide many years of reliability.
- Advanced standardizing technique eliminating the use of a standard cell.
- Accurate setting of the individual alarm set points, read directly on the indicator, provides operational simplicity.
- 1° readability on the T.I. through incremental ranging in 100 degree steps.
- Imperceptible meter error through range suppression in potentiometric type amplifier circuit.
- Alarm memory for momentary alarms.
- Elimination of conventional lockup relays in annunciator circuits.
- Automatic operational check of all circuits including continuity of thermocouples.
- Compact design — 21" wide, 44" high and 16" deep.

**The power supply is packaged separately.*

TOTAL NET PRICE: 40 point unit $4,000 F.O.B. New York, N. Y. $50 per additional point to a maximum of 80 points per unit.

YOURS ON REQUEST: Technical Bulletin #109 fully describing TIM

THE

KYBERNETES®

CORPORATION

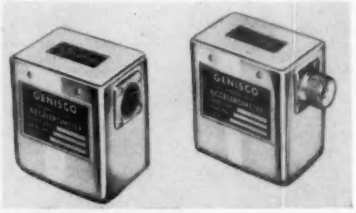
A DIVISION OF SELF WINDING CLOCK CO., INC.
FOR 71 YEARS LEADER IN TIME STANDARDS AND PRECISION ENGINEERING

SALES AND EXECUTIVE OFFICES:
9 EAST 40TH ST., NEW YORK 16, N. Y.

NEW PRODUCTS

brackets are specified in 100-sec increments. The overall time cycle is adjustable in 1-sec increments from zero to one-half the maximum range, and in 2-sec increments from one-half to full range. Intermediate switching events can be preset at any points throughout the full range of the unit in 1-sec increments. The number of events is limited only by the length of the time-cycle settings.—Counter & Control Corp., Milwaukee, Wis.

Circle No. 44 on reply card



G-SENSITIVE

This acceleration-sensitive switch version of the DDL Accelerometer is a magnetically damped, rugged, oil-filled instrument suitable for use in high-speed missile and aircraft instrumentation systems. Available ranges are from plus or minus 0.01 g to plus or minus 30 g's. The switch will open and/or close at any specified g value (or multiple values). Normally-open, normally-closed, or multiple-switch circuits can be provided.—Genisco, Inc., Los Angeles, Calif.

Circle No. 45 on reply card

NEW POLAR RELAY

The MYZA transistorized polar relay is actually a Micropositioner with a built-in transistor preamplifier. It thus requires greatly reduced input power to operate the contacts. Models are

launch!

AC's NEW INERTIAL GUIDANCE SYSTEM—THE ACHIEVER—CAN "TAKE IT"

Literally . . . blasted off the earth . . . then guided with uncanny accuracy by the AC Achiever System. And through all this the precision of the Achiever's moving parts—some of them machined to tolerances in the millionths of an inch—is not affected in the slightest!

Once launched, the Achiever provides Air Force ballistic missiles their "built-in" navigator by compensating for weather and distance. Navigating thousands of miles, the Achiever gives the missile pin-point accuracy!

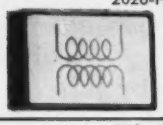
Engineering feats like the Achiever contribute to AC's position of leadership in this complex field of electro-mechanical research and engineering. They account, too, for AC's position as a prime contractor on guidance work for the Air Force in the field of advanced missile systems. Carrying top priority from theory right into production, AC stands ready.

THE ELECTRONICS DIVISION OF GENERAL MOTORS

FLINT, MICHIGAN MILWAUKEE, WISCONSIN

INDICATING LAMPS

2026-F



2026-F

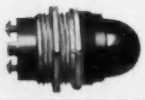
Rectangular lamp with flat lens for engraved (1-3/16" x 3/4") message; all colors. T-3¼ SC miniature bayonet bulb for low voltages, (24V tungston bulb with series resistor for 120/220V) built-in resistor for Neon NE-51 bulb. Single hole (¾") mounted. Frame size 1-13/32" x 31/32".

2026-P

2026-P

Rectangular lamp with prism lens for side visibility. Small message can be engraved on facets, all colors. T-3¼ SC miniature bayonet bulb for low voltages (24V tungston bulb with series resistor for 120/220V) built-in resistor for neon NE-51 bulb. Mounts in ¾" hole. Frame 1-13/32" x 31/32".

659 D/E



659 D/E

Rugged, heavy-duty unit, extremely shallow depth behind panel (1¼") brilliant side visibility. Chrome finish, glass lens, 1⅜" dia. mounting hole. S6 bulb, molded bakelite socket, 6-32 terminal screws. U/L listed.

170 S/P

170 S/P

2" diameter lens, glass or plastic, for engraved message; brilliantly back lighted, one lamp Annunciator for individual or multiple use. Mounting hole 1⅜", S6 bulb, 6-32 terminals in molded bakelite socket. Bright chrome finish. U/L listed.

2-SQ

2-SQ

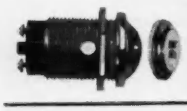
Square lamp, mounts in 1⅜" round hole, ideal Annunciator unit, 1¼" × 1¼" engraving area. Molded frame, 1⅞" square Lamp may be removed from front for servicing. Uses S6 bayonet and screw type bulbs and T-3¼ bulb for low voltages.

T2MC

T2MC

The Engineers unit, uses low-current T2 slide-base bulb, (low as 0.038 amp.). Glass or plastic lens for engraving integral message. Mounts in 19/32" hole. 11/16" OD, molded body.

600



600

Heavy-duty lamp with slip-fit lens cap. S6 bulb, superior appearance, polished chrome finish, Bakelite socket, 6-32 terminal screws. Mounts in 1⅜" hole, curved or flat lens for engraved message. U/L listed.

Recessed Lamp Receptacles for S14-S11-G10

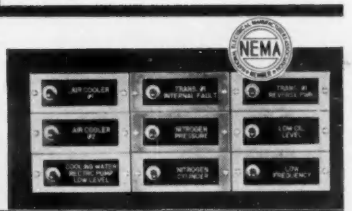
RBE-170 Combination Lamp and Relay

Switch Plate Lamp

Multiple Lamp Units for Back Lighted Messages

ANNUNCIATORS

Lamp annunciators with plug-in relay units. Abnormal conditions of supervised contacts illuminate message panel; steady or flashing lights.



The H. R. KIRKLAND Co., Morristown, N. J.

Serving the Electrical Industry Since 1930

NEW PRODUCTS

available with three types of contact operation: form K or "null-seeking" calibration; form M, known as "memory-type" calibration; and form C, snap-acting calibration. Three types of enclosures can also be supplied. The MYZA relays are designed for a variety of applications in positioning, variable-leg Wheatstone bridge, and speed regulation circuits.–Electrical Components Div., Barber-Colman Co., Rockford, Ill.

Circle No. 46 on reply card

VOLTAGE MONITOR

The Series 2303 Compacts are voltage-sensitive meter relay controls for monitoring voltages. Each unit contains a VHS relay, load relay, and other components needed to continuously monitor or control voltage supplies. Relay action may be manual or automatic reset. Inputs are 10 mv to 500 volts dc or 250 mv to 500 volts ac. Accuracy varies from 2 to 6 percent, depending on temperature and type. Characteristics of the load switch are as follows: SPDT, 5 amp, and 125 vac noninductive. Standard connector is a nine-pin plug-in octal type; AN connectors are optional.–Assembly Products, Inc., Palm Springs, Calif.

Circle No. 47 on reply card

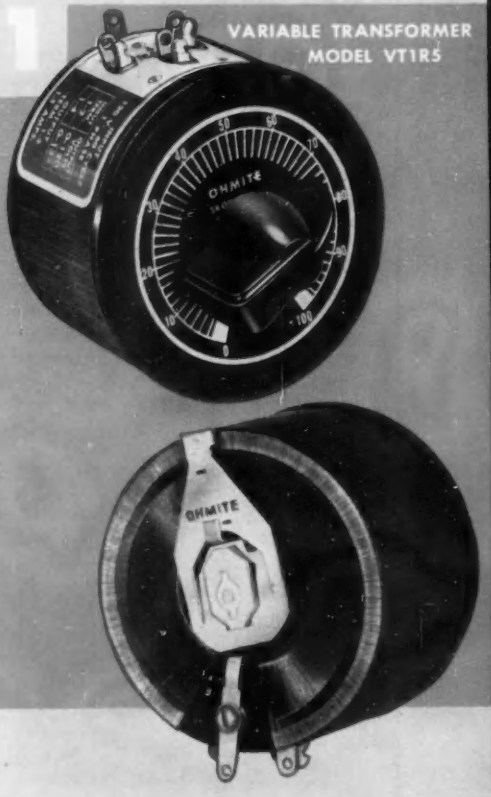
TIME DELAYS

Delay ranges from 5 to 20 sec up to 1 to 5 min are available in a new line of thermal time delay switches, ordinarily used with magnetic relays. Delay can be set at any point within the limits of the timing range by means of an adjustment screw that varies the contact gap. The line includes two types, one providing immediate recycling, the other not. Both can be supplied with

2 new components from OHMITE®

subminiature wire-type tantalum capacitors and variable transformer

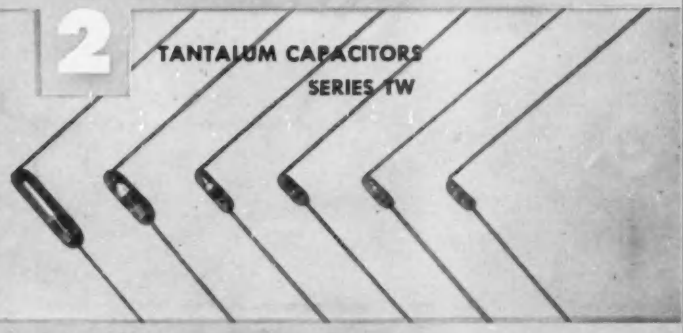
1 VARIABLE TRANSFORMER MODEL VT1R5



MORE CAPACITY FOR EQUAL SIZE

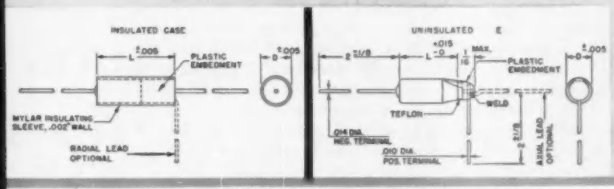
The rating of 1½ amperes represents a continuous rating at any brush setting. This "bonus" in current capacity is the result of a unique core design by Ohmite. The new Ohmite VARIABLE TRANSFORMER model VT1R5 features: Long-wearing, nonoxidizing, rhodium-plated coil contact surface, a ceramic hub that mounts the contact arm, and provides 3000 VAC insulation between parts at line potential and shaft assembly; positive brush to center-lead connection because brush pigtail shunt is bonded into solid copper-graphite slip ring. Input voltage is 120 V, 60 cycle; output voltage is 0-120 V—0-132 V. Mounted by ⅜"-32" bushing and nut. *Write for Bulletin 151.*

2 TANTALUM CAPACITORS SERIES TW



GREATER CAPACITANCE PER UNIT VOLUME

The new Series TW Ohmite subminiature Tan-O-Mite® TANTALUM CAPACITORS are wire-type units that feature greater capacitance per unit volume, lower leakage current and power factor, and small capacitance drop at extremely low temperatures as compared to other types of electrolytics. Ultrasmall for low-voltage DC transistorized electronic equipment, these new tantalum capacitors have *high stability, high capacitance, long shelf life,* and excellent performance under temperature extremes of −55° C to +85° C. They are available in six *subminiature sizes:* 0.1 to 60 mfd. over-all capacitance range.



SIZE	UNINSULATED		INSULATED	
	D (inches)	L (inches)	D	L
T	.075 (5/64)	.156 (5/32)	.082	.203
S	.075 (5/64)	.187 (3/16)	.082	.234
M	.095 (3/32)	.172 (11/64)	.100	.218
A	.095 (3/32)	.250 (1/4)	.100	.312
B	.125 (1/8)	.312 (5/16)	.134	.375
C	.125 (1/8)	.500 (1/2)	.134	.562

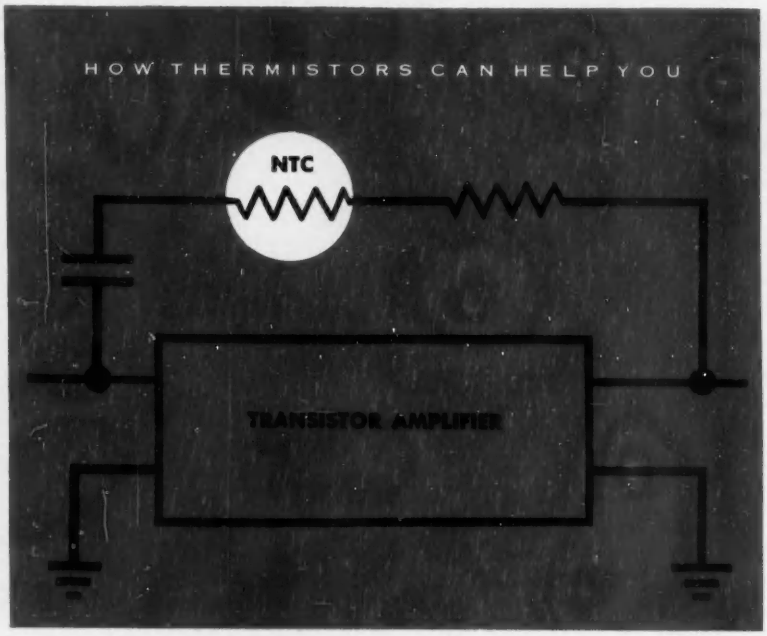
Smallest size is .075 (5/64) x .156 (5/32) inches; the largest is .125 (1/8) x .500 (1/2) inches. Five stock sizes are available in a wide range of capacitances, voltages. Units insulated with a tough Mylar® plastic sleeve can be furnished. *Write on company letterhead for Bulletin 148B.*

BE RIGHT WITH

OHMITE®

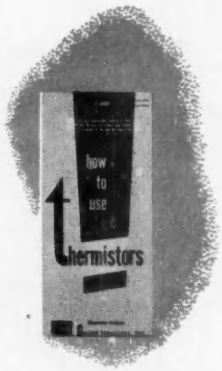
RHEOSTATS • RESISTORS • RELAYS • TAP SWITCHES
TANTALUM CAPACITORS • VARIABLE TRANSFORMERS

OHMITE MANUFACTURING COMPANY
3674 Howard Street, Skokie, Illinois



Compensating for Temperature Effect on Transistors with GLENNITE® Thermistors

Keeping transistor amplifier power gain constant has continually plagued computer design engineers. Recent experimentation using Glennite wafer thermistors has provided a simple, effective solution to this problem.
A temperature increase in the transistor amplifier circuit shown above causes an increase in power gain. To maintain constant gain, a Glennite wafer thermistor is placed in the feedback circuit. Negative temperature coefficient of the thermistor causes a decrease in resistance as the temperature increases. The resultant feedback degeneration compensates for the gain.
Transistor gain control in computers is one of innumerable applications for versatile Glennite Thermistors. Wafer, bead, and rod configurations offer inexpensive solutions to thousands of temperature sensing, temperature compensation, amplitude control, measurements and analyses, and time delay problems.



Write for "HOW TO USE THERMISTORS." It outlines solutions to many of the above problems.

Thermistor Division
Gulton Industries, Inc.
METUCHEN, NEW JERSEY

NEW PRODUCTS

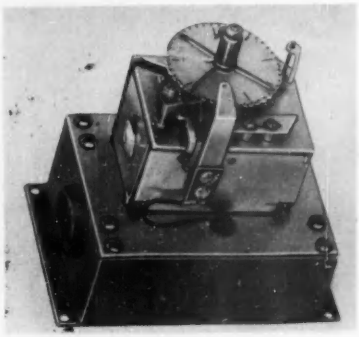
contacts rated at 1 or 2 amps, 115 vac. —Betts & Betts Corp., New York, N. Y.

Circle No. 48 on reply card

VARIABLE TIMER

The PM-47 Timer provides a settable time delay between 0.3 and 10 sec with an accuracy of plus or minus 5 percent and an output energy greater than 35,000 ergs. Temperature ambients from minus 70 to plus 165 deg F, and accelerations up to 100 g's are said to have no effect on its operation. The timer is suitable for use in missile and aircraft systems, sled timers, programming devices, and explosive-element initiation. Transient circuits are used to get the proper time delay.—Patterson, Moos Div. of Universal Winding Co., Jamaica, N. Y.

Circle No. 49 on reply card

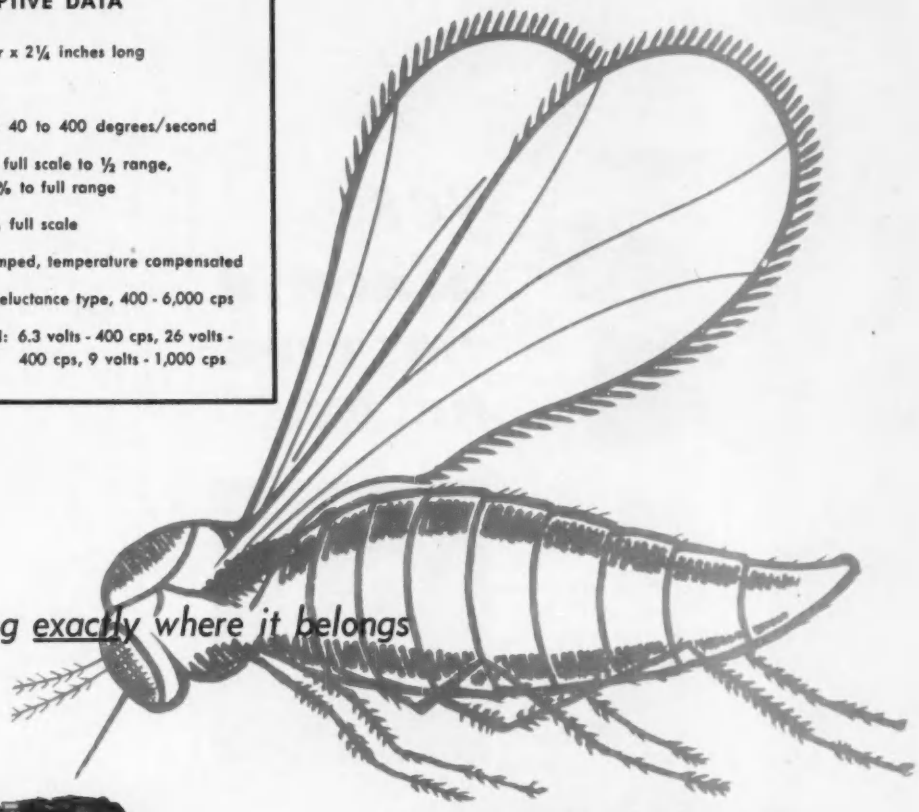


COMPACT SELECTOR

The Secode type 49 Selector, an electromechanical switch responsive to dc pulses, is designed to close its contacts only upon receipt of a specific sequence of pulses, rejecting all others. It responds to pulses with a minimum duration of 0.05 sec, spaced 0.03 to 0.1 sec apart, and occurring at a rate of 4 to 20 pulses per second. Maximum pulse duration is not critical, and power requirement during pulsing is 5 watts. The combination of

DESCRIPTIVE DATA

- **SIZE:** 1 inch diameter x 2¼ inches long
- **WEIGHT:** 3.8 ozs.
- **FULL SCALE RANGE:** 40 to 400 degrees/second
- **LINEARITY:** 0.1% of full scale to ½ range, within 2% to full range
- **RESOLUTION:** 0.01% full scale
- **DAMPING:** Fluid damped, temperature compensated
- **PICKOFF:** Variable Reluctance type, 400 - 6,000 cps
- **MOTOR EXCITATION:** 6.3 volts - 400 cps, 26 volts - 400 cps, 9 volts - 1,000 cps



Putting the sting exactly where it belongs

Gnat Rate Gyro
Shown actual size

GOLDEN GNAT

Miniature Rate Gyros for Missiles and Aircraft

Here is a precision, miniature rate gyro. It's tiny . . . measures only 1 inch in diameter and 2¼ inches in length. It's rugged . . . withstands 100G shock and 10G vibration to 2,000 cps. It has a record of proven performance.

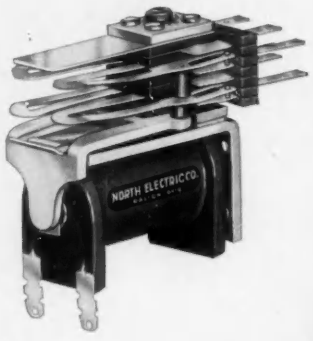
Even under the most severe environmental conditions the Golden Gnat will perform as required. To make this possible many unique design details have been incorporated. One such detail is the Gnat's *gold plated* steel housing for improved corrosion resistance and positive hermetic sealing.

Wherever the need exists for high performance miniature rate gyros such as for autopilot stabilization in missiles and aircraft, antenna stabilization and fire control applications, the Golden Gnat is ideally suited. Write for Bulletin GN . . . Minneapolis-Honeywell, Boston Division, Dept 34, 1400 Soldiers Field Road, Boston 35, Mass.

MINNEAPOLIS **Honeywell**

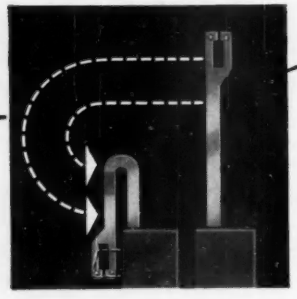
BOSTON DIVISION

telephone | *quality in a miniature relay?*



yes!

IN NORTH "M" TYPE RELAY!



Note the "U" shape of the lever springs. From the pile-up, the lever spring extends the full length of the coil, then doubles back an equal distance to the fixed contact points.

Stability of operating characteristics, with which relay dependability is achieved, can be maximized by a configuration which puts the fixed contact springs as close as possible to the clamping axis of the pile-up and yet escapes the penalty of the greatly foreshortened lever spring common in miniaturized relays.

In the North "M" Relay, both requirements have been met.

The fixed contact springs are lateral extensions from the anchoring pile-up, minimizing any possibility of post-adjustment variation.

The unique "U" design of the lever springs in North's "M" Relay enables it to meet critical space requirements while retaining lever spring length to achieve telephone dependability.

The armature in North's "M" type relay operates on a knife hinge—never needs lubrication, and the small amount of armature travel provides fast operation.

Lightweight operating parts keep contact bounce at an absolute minimum.

North's "M" type relay can be furnished with 6, 12, 24, 48, or 100 Volt coils; 1, 2, or 4 DPDT standard spring arrangements; with double gold or single silver contacts; with dust cover and octal mounting plug.

North's "M" type relay is available from stock.

Length 1-13/16", Height 1-1/4", Width 25/32", Weight 1.8 oz.

INDUSTRIAL DIVISION

NORTH ELECTRIC COMPANY

749 SOUTH MARKET STREET • GALION, OHIO

Available in Canada through Ericsson Telephone Sales of Canada, Ltd., Montreal 8, P. Q.

NEW PRODUCTS

pulses required can be changed in less than a minute without the aid of tools. Over 100,000 combinations are possible. Applications include telephone signaling, remote control systems in which a telephone dial or automatic code sender is used to transmit commands, and computing systems. As used in the latter, it actuates equipment upon receipt of a specific sequence of pulses. The unit weighs less than 2 lbs and will easily fit in the palm of a hand. Prices range from $62.50 depending on the coil and contact combination specified.—Electrical Communications, Inc., San Francisco, Calif.

Circle No. 50 on reply card

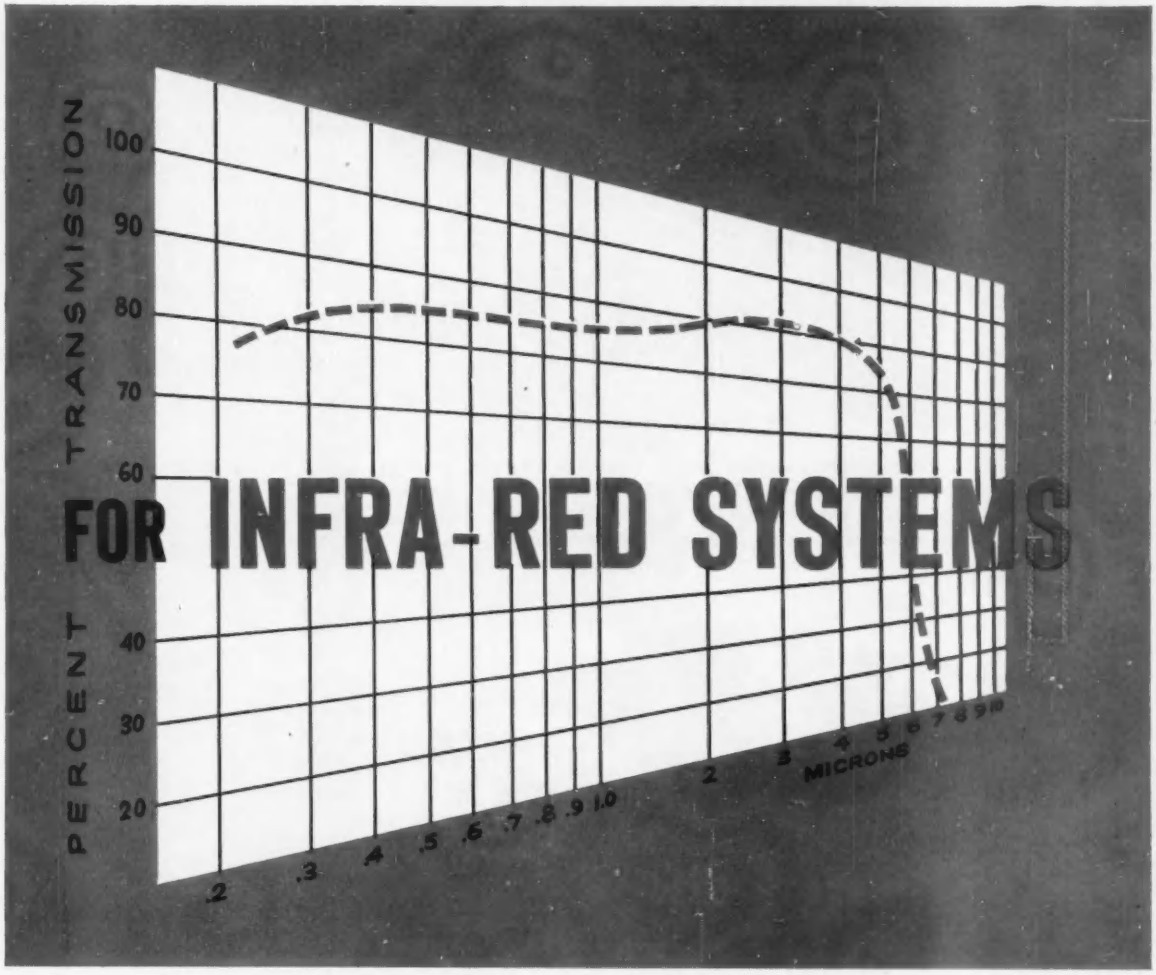
HIGH RATING

Occupying only 0.18 cu in., this subminiature relay features full ⅛ in. silver or palladium contacts handling 3 amp resistive load standard, and 4 amp intermittent. A permanent magnet in an electromagnetic circuit provides the extra armature torques needed to overcome high-contact pressures and to actuate large contacts. No pivots, hinges, or bearings are used in the balanced armature. Three relay types are available. The unit shown, dc SPDT with standard pull-in at ⅓ watt, has vibration resistance 30 g to 500 cps, and 20 g to 2,000 cps.—Luther Mfg. Co., North Hollywood, Calif.

Circle No. 51 on reply card

PRESSURE SWITCH

The inexpensive but reliable GIS-8000 industrial pressure switch, designed for machine tool control panels, hydraulic test stands, and lubrication systems, measures 2½ in. in diam by 2¼ in. high. A sealed pressure sens-



FOR INFRA-RED SYSTEMS

SPECIFY LINDE Sapphire

TRADE-MARK

LINDE Sapphire is . . .

Hard—Moh 9

Transparent, single crystal, pure aluminum oxide

Nonporous—0% porosity

Easily sealed to metals and ceramics

Priced competitively with sintered materials

LINDE Sapphire has . . .

Strength at elevated temperatures

High melting point—2040° C.

Excellent IR transmission at high temperatures (above 500° C.)

LINDE Sapphire is available as . . .

Windows

Domes

Rods and tubes

Special shapes—to order

For more information about LINDE Sapphire . . . Write "Crystals Dpt. CF-9." LINDE COMPANY, Division of Union Carbide Corporation, 30 East 42nd St., New York 17, N. Y. *In Canada:* Linde Company, Division of Union Carbide Canada Limited

Linde

UNION CARBIDE

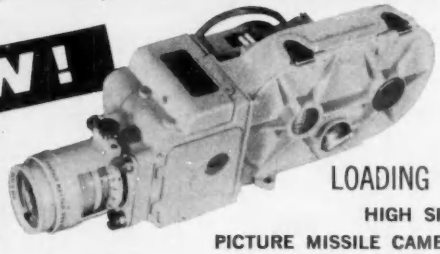
ENGINEERS AND SCIENTISTS interested in working in Synthetic Crystal Sales & Development, contact Mr. A. K. Seemann, Linde Company, 30 E. 42nd St., New York 17, N.Y.

The terms "Linde" and "Union Carbide" are registered trade-marks of Union Carbide Corporation.

NEW! NEW! NEW!

FOR HIGH SPEED
MOTION PICTURE PHOTOGRAPHY

NEW!



DAYLIGHT
LOADING FASTAIR...

HIGH SPEED MOTION
PICTURE MISSILE CAMERA

This 16mm Camera accepts standard daylight loading spools in the *new* 50′ and 100′ magazines . . . will withstand extremely high "G" loads in acceleration, vibration or shock. A full complement of lenses is now available.

NEW!

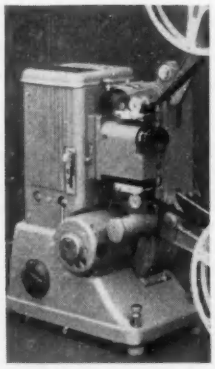
100 *FASTAX*
COMBINED MOTION
PICTURE AND
OSCILLOGRAPHIC CAMERA

. . . where economy is a factor. Features 100′ daylight loading spools . . . speed ranges from 150 to 8,000 pictures per second . . . can take pictures or oscillographic recordings simultaneously or independently . . . three cameras in one.

NEW!

8mm or 16mm
MOTION PICTURE
ANALYSIS PROJECTORS

. . . for study and analysis of subjects filmed at high speeds. Projection without flicker as slowly as 2 frames per second. Normal projection (16 f.p.s.), frame by frame or still picture projection may be shown.



WRITE for more detailed information. Inquiries welcome.

FASTAX DIVISION
WOLLENSAK
OPTICAL COMPANY
Rochester 21, N. Y.

NEW PRODUCTS

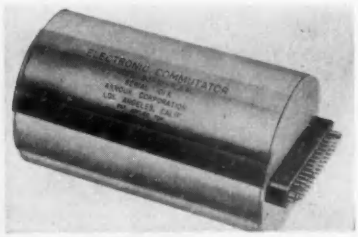
ing chamber contains a diaphragm suitable for a variety of fluids and gases. Factory pre-set, the switch will make or break electrical loads of 110/220 volts to 15 amp in response to pressure changes up to 225 psi. Gorn Electric Co., Inc., Stamford, Conn.

Circle No. 52 on reply card

FOR INDUSTRIAL USE

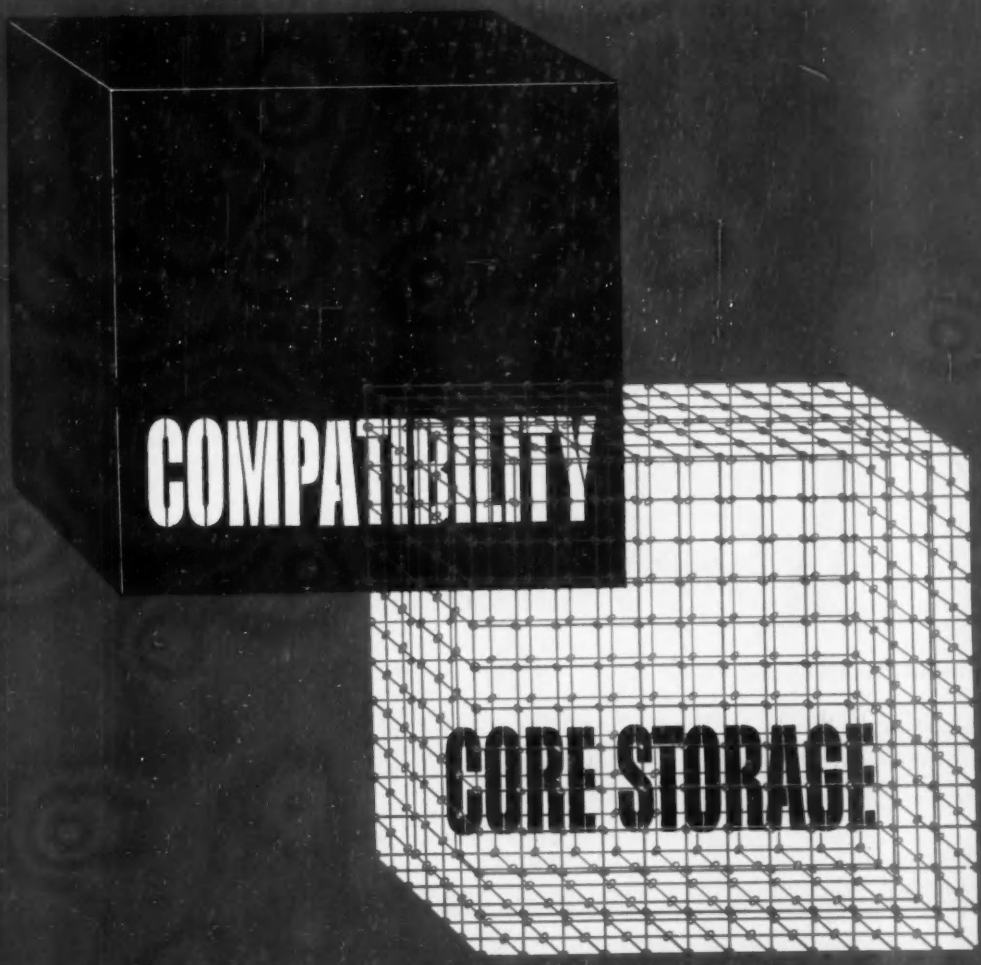
Shown is a miniature photoelectric relay designed for reliability, minimum maintenance, and low cost. It plugs into a 120-volt line and needs no tubes or transistors. A high-speed sensitivity relay, power supply, and photocell lens assembly are all contained in a cast-aluminum case 4¼ by 2⅛ by 1⅛ in. The device sells for $35. Plug-in and splice box types are available.—Tri-Tronics Co., Bellwood, Ill.

Circle No. 53 on reply card



ELECTRONIC COMMUTATOR

The Series ETC-30 Electronic Commutator, developed for airborne tele-



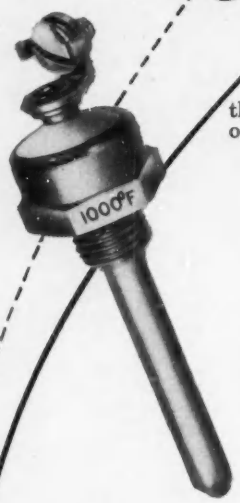
Compatibility and core storage... we're proven specialists in both and enjoy a solid record of accomplishment. Our unique experience gained in pioneering magnetic core memories has resulted in advanced facilities for the manufacture of ferrite cores and systems based on magnetic core technology. Completely transistorized magnetic core memories, core buffer units and tape-to-tape conversion systems are currently in production... equipment that provides greater compatibility and balance in data handling systems. If your specific application calls for magnetic cores, core matrices, buffers, memories, tape translation or special purpose digital data processing systems, call in our technical representatives.

TELEMETER MAGNETICS Inc.

2345 Pontius Avenue, Los Angeles 64, California

Write for detailed information on Model No. 1092-BU-7R Magnetic Storage Buffer.

New CPI thermal switch is *Light and Lively*

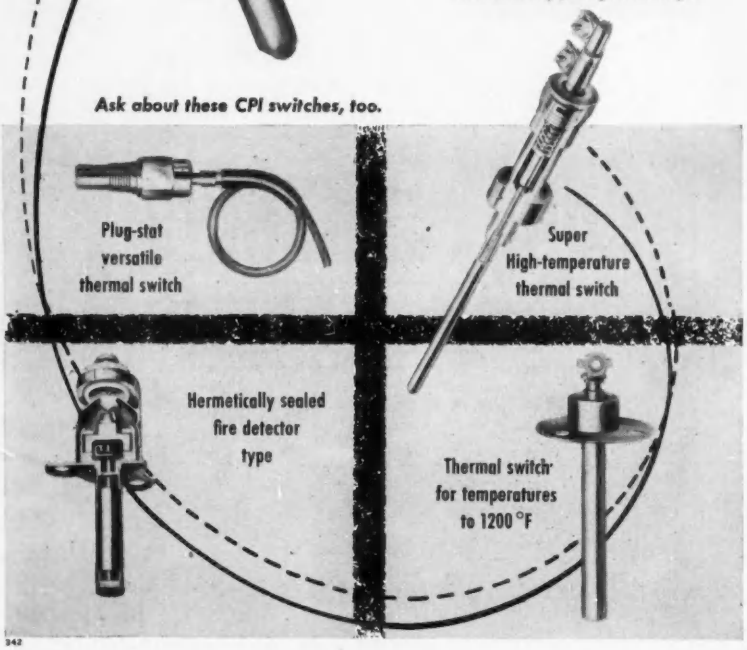


This new lightweight (weighs less than one ounce) thermal switch features an operating differential of plus or minus only one degree with extremely fast response.

With an effective calibration temperature rating from −20°F +1000°F, it will even operate accurately when subjected to momentary undershoots to −80°F and overshoots to as high as 2000°F.

Wherever fast-acting, sensitive, thermally responsive regulation is required for control of dangerously high or low temperatures, this "LIGHT and LIVELY" switch will do the job accurately, dependably.

Ask about these CPI switches, too.


Plug-stat versatile thermal switch
Super High-temperature thermal switch
Hermetically sealed fire detector type
Thermal switch for temperatures to 1200°F

342

Ask our representative to tell you how CPI can help you solve your temperature control problem—and remember—when temperatures are high (or low) you can depend on CPI. Write for complete engineering data. Ask for catalog CE

Control products, inc.

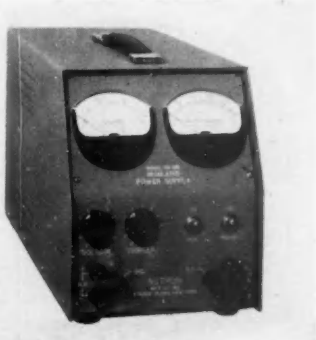
HARRISON, N.J.

NEW PRODUCTS

metering application, is offered with sampling rates ranging from 75 to 900 points per sec. It may be used as a direct replacement for mechanical commutators in 0-3 volt and 0-5 volt systems. Errors due to drift, cross-talk, and nonlinearity are less than 0.5 percent. The unit is designed to give noise-free operation, without maintenance of any kind, for at least 5,000 hours. Features include 27 information channels, 1 master pulse, and a built-in signal limiter. Power required is 150 vdc at 12 ma. The unit measures 3 in. in diam by 5 in. long and weighs less than 2 lbs.—Arnoux Corp., Los Angeles, Calif.

Circle No. 54 on reply card

POWER SUPPLIES



VERSATILE SUPPLY

Here is a portable power supply for laboratory, field, and industrial use that combines ruggedness and compactness with the accuracy of a precision instrument. Features include a continuously variable output, a high-voltage vernier adjustment, and a well-designed case. The two available models—the PR-100 and the PR-200—take an ac input of 105 to 125 vac, 50 to 60 cps. The dc output is 120 to 300 volts (0 to 100 ma or 0 to 200 ma, depending on the model), and the ac output is 6.3 volts (3 or 6 amps, again depending on the model). Regulation is within 0.1 percent for line variations from 105 to 125 vac, and for no-load to full-load. Internal impedance is less than 2 ohms; ripple, less than 10 mv.—Nutron Mfg. Co., Staten Island, N. Y.

Circle No. 55 on reply card

Progress Report on New Computer Developments

Now General Electric Offers You Complete Computer Machine Time and Computer Services

AT YOUR SERVICE: AN EXPERIENCED STAFF AND THE NEWEST COMPUTER

Immediate assistance in the form of a complete range of General Electric computer services is now available to business, industry and government. Facilities include an IBM 704 Computer having high-speed, random-access core storage of 8192 words, magnetic drums, and ten magnetic tape units. The peripheral equipment provides for complete flexibility in selecting the input and output media.

A staff of 70 specialists which includes leaders in the computer applications field can provide immediate assistance in solving your problems. In addition to supplying the most versatile programming services, the staff is eminently qualified to perform advanced work in the following:
Mathematical Analysis . . . Operations Analysis . . . Simulation

These are resources with which you can supplement the capabilities of your present staff and facilities.

1 | 2 | 3

The three basic areas of General Electric's Computer Service:

1. COMPUTATION SERVICE
G.E. supplements your present computing capabilities by handling problem overflow resulting from the fact that your own computer time and personnel are scheduled far in advance.

2. DATA PROCESSING SERVICE
G.E. provides complete data processing service, including the submission of interpretive reports to fulfill your exact requirements. Machine time is now available for either single or recurring tasks.

3. REQUIREMENTS EVALUATION
G.E. can evaluate your requirements for data processing and assist you in selecting the correct computer for the task. In addition G.E. will coordinate the installation, develop the program and train personnel to operate the computer.

For complete information contact: General Electric Company, Computer Department, Marketing Section, 1103 North Central Avenue, Phoenix, Arizona.

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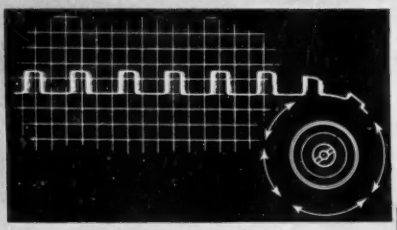
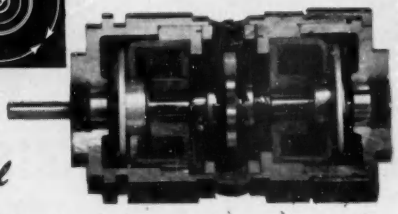
GENERAL ELECTRIC

CPA-2 (6-57)

STEPPER MOTOR





PROVIDES

Bi-Directional

PROPORTIONAL SHAFT ROTATION FOR A GIVEN PULSED INPUT

MODEL SM-300-1

- Angular increment per pulse — 36°.
- Stepping rate — up to 15/second.
- Voltage requirement — 28 V. D.C.
- Duty cycle — $\left(\frac{\text{on time}}{\text{on time \& off time}}\right)$ 56% max.
- Weight — 8 oz.
- Shock — 15 G's for 11 milliseconds duration each way along three major axes.
- Reliability — shall not fail to convert more than one pulse in 1,000,000 into equivalent angular rotation.

OTHER MODELS AVAILABLE WITH VARIATIONS FROM THE ABOVE SM-300-1 SPECIFICATIONS.

The two rotary solenoids contained in each motor produce the incremental motion of the output shaft in either direction. Energizing either of these solenoids produces a combination of linear and rotational motion which moves a ratchet gear axially into engagement with its mating ratchet gear and thus imparts a constant amount of rotation to the output shaft. The detent roller assembly insures consant, reproducible angular shaft rotation increments in either direction and maintains the output-shaft position while the motor is at rest with the power off.

Stepper Motors are adaptable to routine jobs such as driving mechanical counters. They also find excellent use in positioning devices that will set up a controlling voltage and/or a phase shift such as potentiometers and autosyns. They are widely used as a positioner for guided missiles to adjust heading, fuel flow, altitude, and circuit sampling for telemetering purposes. In one adaptation as a heading controller, two Stepper Motors are used to position a differential autosyn in steps of either vernier degree or coarse degrees per input pulse, bi-directionally, through a suitable gear train.

Write for more details—available upon request.

STEPPER MOTORS CORPORATION

Subsidiary of California Eastern Aviation, Inc.

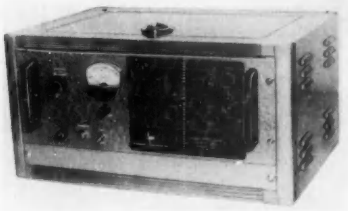
7444 West Wilson Avenue • Chicago 31, Illinois

NEW PRODUCTS

REGULATED DC

Voltages range from 3 to 350 vdc and current ratings from 50 ma to 20 amperes in this brand new transistorized dc power supply, said to be suitable for applications requiring precise, transient-free power. Fixed and variable voltage units are available. Features include high efficiency, low heat dissipation, instant warmup, and extremely long life.—Perkin Engineering Corp., El Segundo, Calif.

Circle No. 56 on reply card



BRIDGE SUPPLY

This filtered, transistor-regulated power supply is designed primarily for a 120-ohm strain gage bridge. And since its output is located on the front panel, it can be used for other applications too. Specifications of the compact unit include: internal impedance, less than 0.25 ohm; ripple, less than 0.1 percent of the output voltage; and output range, 0 to 25 vdc, 500 ma.—Spar Engineering & Development, Inc., Wyncote, Pa.

Circle No. 57 on reply card

ELECTRONIC BATTERY

Designed to replace widely-used storage battery and floater combinations for spectrophotometers, sensitive dc amplifiers, and other applications requiring stability and, low noise level, the Model 170 Electronic Battery has either a 6- or a 2-volt output. At 6 volts, ripple and noise represent 1 mv

FIRST TWIN DIODE...

Designed especially for computers

RCA-6887 Cuts Heater Power

Combining exceptional dependability, small size, and a low-wattage heater (1.26 watts)...the new RCA-6887 performs with high efficiency on *one third less heater power* than conventional twin diodes. This new tube offers up-to-date advantages for compact, medium-speed switching circuits.

Among the many design features of the RCA-6887 contributing to long life and high dependability are a pure-tungsten heater, special-alloy cathodes which retard interface, high-purity nickel plates, plus a protective shield to minimize interelectrode leakage. Each cathode utilizes a separate base pin to permit flexibility of circuit arrangement.

Strict production controls based on typical electronic computer conditions, extreme care in selection and inspection of materials, and rigorous tests for shorts and leakage—assure uniformity of electrical characteristics and stability initially and throughout life.

RADIO CORPORATION OF AMERICA
Tube Division Harrison, N. J.

Investigate the many advantages RCA-6887 offers your medium-speed electronic computer designs. Contact your RCA Field Representative at the RCA District Office nearest you

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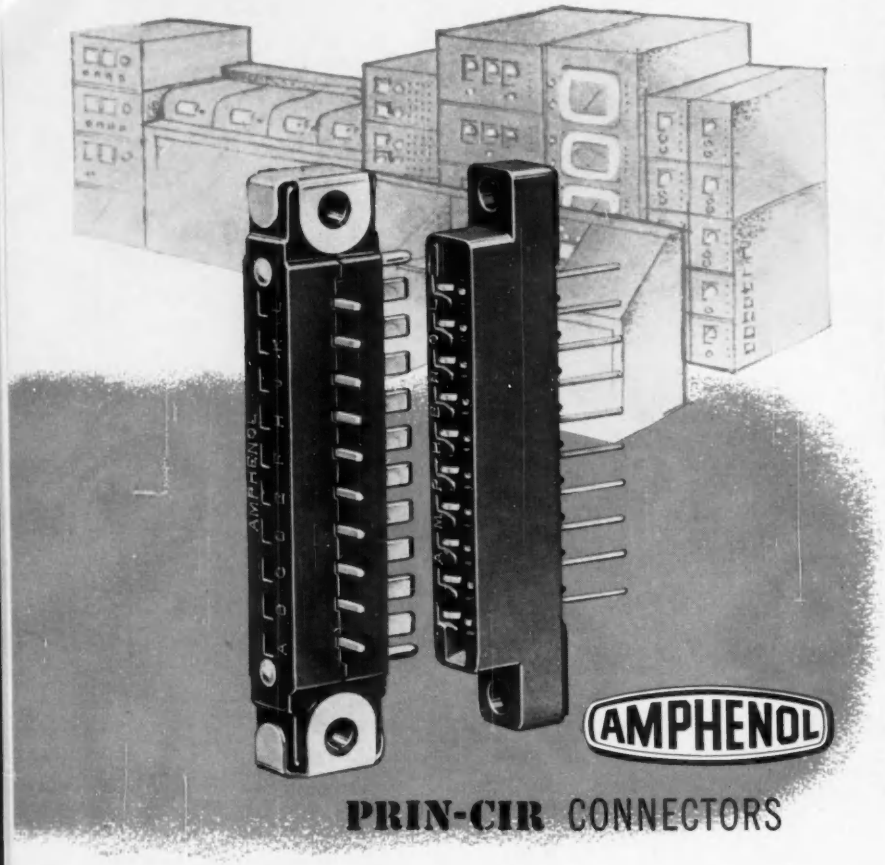
744 Broad Street
Newark 2, N. J.

MIDWEST: WHitehall 4-2900
Suite 1181
Merchandise Mart Plaza
Chicago 54, Ill.

WEST: RAymond 3-8361
6355 East Washington Blvd.
Los Angeles 22, Calif.

For technical data on RCA-6887, write RCA Commercial Engineering, Section 1-56-Q Harrison, N. J.



PRIN-CIR CONNECTORS

Connecting printed circuits with AMPHENOL Prin-Cir components assures both ease of operation and high performance reliability. Available as plugs and receptacles, Prin-Cirs feature rugged, smooth-working gold-plated contacts and tough diallyl phthalate bodies. Application versatility is provided through a wide choice of contact terminals: Standard, Pin, Wire Wrap and Open End in receptacles; arrangements allowing for straight or angled board attachment, modular design, and cable plug-in for plugs. Plugs and receptacles available in 10, 15, 18 and 22 contacts; 6 contact receptacle also available.

Average voltage breakdown between contacts at sea level is 5400 V. DC for receptacles and 2300 V. DC for plugs.

AMPHENOL ELECTRONICS CORPORATION
chicago 50, illinois
AMPHENOL CANADA LTD. *toronto 9, ontario*

AMPHENOL

AMPHENOL Industrial Distributors carry stocks of standard AMPHENOL components in order to provide immediate service on your rush requirements

NEW PRODUCTS

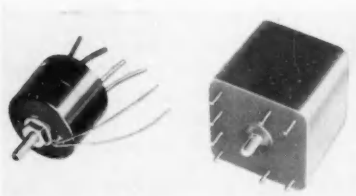
rms maximum; at 2 volts, 0.5 mv rms max. Recovery time of the unit is 0.001 sec, and line regulation for both units is 0.01 percent max. Input is 105-125/210-250 volts, 50 or 60 cps.—American Electronics Laboratories, Inc., Philadelphia, Pa.

Circle No. 58 on reply card

LIGHTWEIGHT POWER

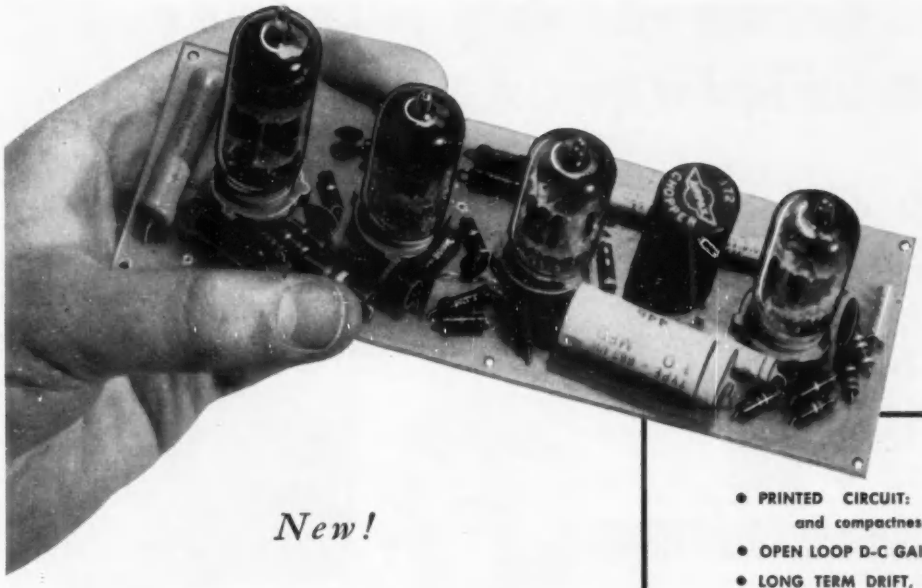
This compact, adjustable dc power supply, specifically designed for bench experiments, features a wide dual output range: high, from 125 to 300 volts, and low, from 0 to 150 volts. A 150-ma current is available throughout these ranges, as is a fixed supply of 150 volts, 50 ma. In a standby position, the B-plus and bias voltage is disconnected and the filament power is left on. The filament voltage consists of two 6.3-volt windings at 2 amp. It can be arranged in series or parallel.—Specific Products, Woodland Hills, Calif.

Circle No. 59 on reply card



PULSE TRANSFORMERS

Highly reliable, encapsulated, hermetically sealed pulse transformers are now being made to rigid military specs (such as MIL-T-27). They operate at



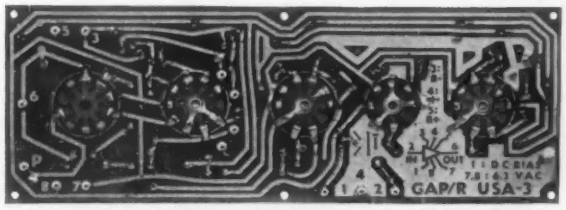
New!

Greater System Accuracy

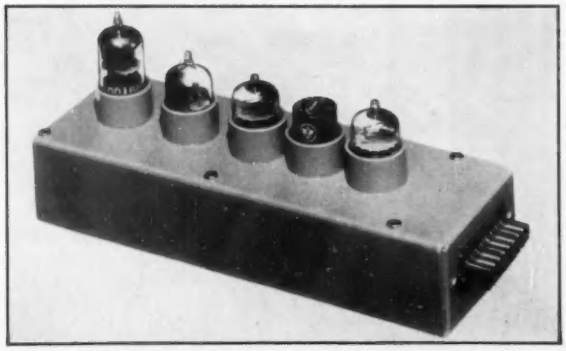
and Reliability with the

- **PRINTED CIRCUIT:** Economy, reliability and compactness.
- **OPEN LOOP D-C GAIN:** 10 million.
- **LONG TERM DRIFT, NOISE and OFFSET:** under 100 microvolts.
- **OUTPUT VOLTAGE RANGE:** ±115 volts.
- **SIZE:** 7" x 2½" board.
- **MOUNTING:** Any convenient method.
- **PRICE:** $95.00.

PHILBRICK *PRINTED CIRCUIT* AMPLIFIER



Underside of Model USA-3 showing printed circuit, amplifier connection scheme, and connecting terminals.



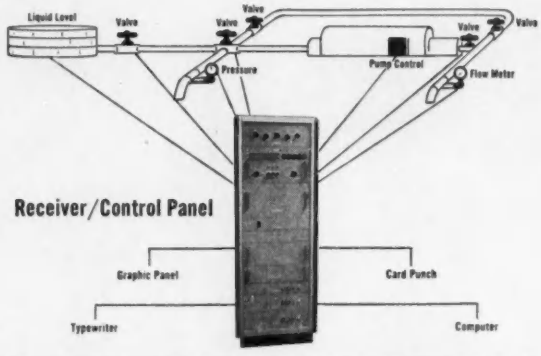
Model USA-3 showing one of the several types of modular packaging available at extra cost.

Model USA-3

High performance combined with the reliability and compactness of a printed circuit design are featured in the new Philbrick Universal Stabilized Amplifier, Model USA-3. It is ideally suited for applications to instrumentation, control and analog computation. Extremely high open-loop d-c gain, wide bandwidth, low noise and wide output range are important performance characteristics of this new chopper stabilized amplifier. An interesting design feature makes this instrument safe against self-destruction, even under prolonged overload conditions or direct grounding of its output. At a price of only $95.00, it offers more performance per dollar than any other amplifier on the market today. *Write to George A. Philbrick Researches, Inc., Dept 10, for Bulletin USA-3.*

GEORGE A.
PHILBRICK
RESEARCHES, INC.
230 Congress Street, Boston 10, Massachusetts

Automatic Monitoring and Control of ANY Remote Pipeline Operation



with

Bendix-Pacific

ELECTRO-SPAN

THE LOW COST DIGITAL SYSTEM

Electro-Span Systems are accurate, reliable digital data transmission systems for pipeline telemetering and supervisory control.

Any number of remote pump stations or functions can be controlled from one or more control locations with these Bendix engineered systems.

The functions of control, indication, data-logging, and monitoring can be provided singly or in combination, providing the most accurate, efficient and inexpensive use of standard communication links.

Write for the new brochure which fully describes these pipeline supervisory control and data-logging systems. Please request Bulletin ES-12.

VERSATILE TANK GAUGING SYSTEMS

Any number of tanks can be measured and controlled by the Bendix digital pulse-code system. The receiving equipment can indicate tank liquid level in feet, inches and eighths as well as temperature by tank number and can scan several tank farms automatically. Write for Bulletin ES-5A for full information.

Department 432

Bendix

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Bendix Aviation Corporation

NORTH HOLLYWOOD, CALIF.

Export — Bendix International, 205 E. 42nd Street, New York 17, N. Y.
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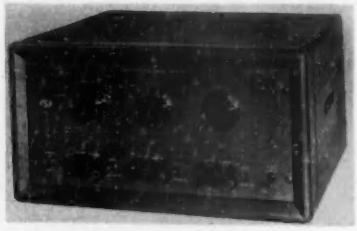
NEW PRODUCTS

ambient temperatures up to 85 deg C. Also available are subminiature units for printed, transistorized, and miniaturized circuit applications. All models meet standard voltage, life, pull, temperature, immersion, and moisture resistance tests—Telex, St. Paul, Minn.

Circle No. 60 on reply card



TWO-PHASE SUPPLY

Designed for the development and testing of servos, servomotors, two-phase gyro motors, torquers, and other 400-cycle components, this new two-phase power supply has a conservatively rated power output of over 500 va. All outputs are continuously variable; of these, two in-phase allow separate excitation of pickoffs, tachometers, or motor reference phases when the instrument is used for system development. All input and output lines are fused individually—the output lines with indicating fuse posts. An input switch, on the back of the instrument, makes possible the use of either 115- or 200-volt line-to-line supply voltage. —Pacific Technical Co., Los Angeles, Calif.

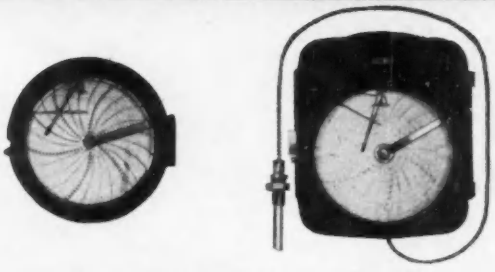
Circle No. 61 on reply card

SIMPLIFIES VALVING

The new ISO-FLO hydraulic pump shown above is essentially a radial piston pump (7 or 14 pistons) with the discharge manifold so modified as to isolate the power output of one or more pistons from the output of the others. Thus, two or more inde-

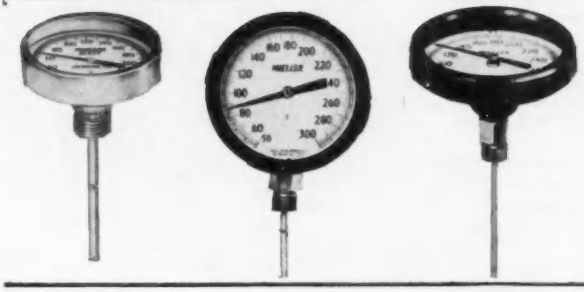
For Easy Accurate Reading...

MOELLER THERMOMETERS



RECORDING THERMOMETERS

Mercury Actuated, made in round or rectangular cases. Charts 10" or 12", 1-hour, 12-hour, 24-hour or 7-day. Ranges from minus 40° to plus 1000°F. or its equivalent in Centigrade. Made in remote reading, direct reading, portable and self-contained styles. Plain stems, union connection stems, and separable sockets in all stem lengths and alloys.

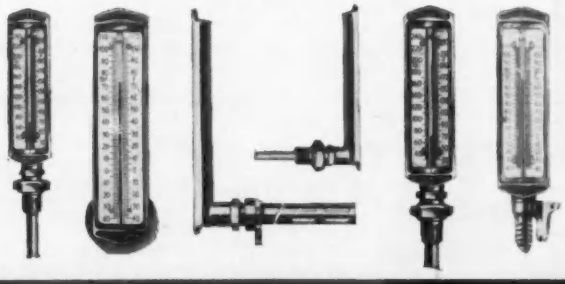


MOELLER BIMET THERMOMETERS

Are actuated by a powerful, specially processed bi-metal helix. Made with 3" and 4½" diameter dials. Stainless stems, can be furnished with union connection or separable sockets. Scale ranges from minus 100° to plus 1000°F.

DIAL INDICATING THERMOMETERS

Mercury Actuated, made in 4½", 6" and 8½" sizes with flexible extension tubing. Adjustable rigid stems, single or two pointers, with or without electrical contacts, plain bulb, union connection bulb or separable sockets in all lengths and alloys. Scale ranges from minus 40° to plus 1000°F. or its equivalent in Centigrade.



MOELLER INDUSTRIAL THERMOMETERS

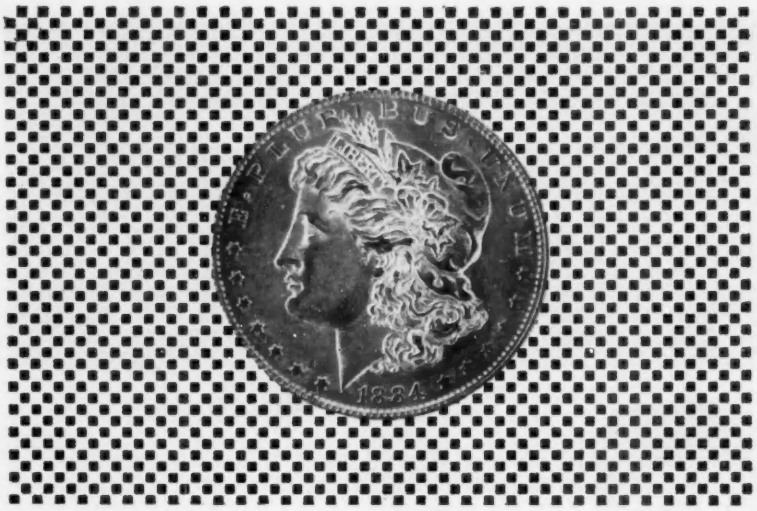
Made in all forms — Straight, Angle, Right Side Angle, Left Side Angle, Reclined and Inclined Angles, in scale ranges from minus 120° to plus 1125°F. or its equivalent in Centigrade. Available in 5", 7", 9" and 12" scale sizes with plain stems, union connection stems and separable sockets in all stem lengths and alloys.

Send for Literature on these Moeller Products and Recording Pyrometers, Test Wells, Hydrometers, Fingered Stem Thermometers, and Vacuum Gauges.

MOELLER INSTRUMENT COMPANY

SINCE 1867

RICHMOND HILL 18, NEW YORK CITY



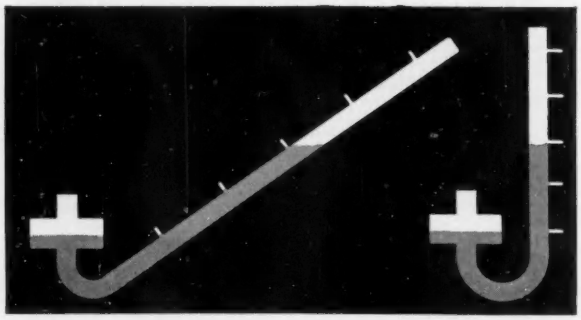
more points per dollar

Expanded scale readings . . . increased sensitivity

Inclined manometers give expanded scales, greater sensitivity and greater readable accuracy to any measurement application. Note the comparison of scale lengths for vertical and inclined manometers of equivalent ranges. It demonstrates just one phase of the versatility you have when you know and use manometer instrumentation.

With manometers, the same budget will cover more points of measurement on your flow chart . . . AND at each point, you will get *more* accuracy, *more* readability, *more* dependability.
Where else can you find the lowest cost instrument with the highest accuracy rating?
—or a rugged industrial instrument which inherently possesses test laboratory accuracy and elegance?
—and whose performance is right out in the open . . . literally verified before your eyes?
Dollar conscious all the way, a manometer costs next to nothing to maintain and absolutely nothing to operate.

Bulletin G-14,
an informative guide to manometers,
is yours for the asking.
The Meriam Instrument Co.,
10920 Madison Avenue, Cleveland 2, Ohio.



FLOWS · PRESSURES · VACUUMS · LEVELS · DIFFERENTIALS

MERIAM MANOMETERS
...always accurate

pendent flow rates are obtained by the use of only one pump and motor, and wide variations between the flow rates are easily accomplished. By adapting separate relief or pressure control valves to the several flows, a single pump can handle up to 10,000 psi and a variety of hydraulic operations without complex valving.—Simplex Engineering Co., Zanesville, O.

Circle No. 62 on reply card

LOOKS LIKE DRY CELL

This new constant-voltage reference supply, Model CVR-10, designed to take the place of No. 6 dry cells in instruments and controls, provides an output of 1.5 vdc at 6 ma with 0.25-percent stability over input variations of 108 to 125 volts. It resembles a No. 6 dry cell in every respect, including knurled positive and negative terminals. Two 30-in. leads, with lugs, provide for quick connection to the 115-volt line terminals. A lugged 20-in. lead connects to the ground. No modifications or special tools are needed for the installation.—Performance Measurements Co., Detroit, Mich.

Circle No. 63 on reply card

ROTATES EITHER WAY

A new precision bidirectional stepping motor that translates pulses to incremental shaft positions is now available for rotating potentiometers, counters, rotary switches, and control mechanisms. This new motor features a special magnetic clutch, rather than ratchets, to index the shaft. Clutch and

CLEVITE POWER TRANSISTORS

EXPANDED LINE OF POWER TRANSISTORS FOR AUDIO OUTPUT, POWER SUPPLY AND SWITCHING APPLICATIONS

Clevite Power Transistors, available in production quantities, offer:

- **HIGH POWER RATINGS**
- **HIGH POWER GAIN**
- **LOW DISTORTION**
- **LOW THERMAL RESISTANCE**
- **RUGGED WELDED PACKAGE**
- **HERMETIC SEAL**

Check the outline specifications for the type of performance you get from Clevite Power Transistors.

For on-the-job help with specific application problems, our engineers are available for consultation.

Data sheets B-211, B-214 and B-216 provide all the facts on Clevite Power Transistors. Write for your copies.

Outline Specifications

Type	Military 2N297	CTP 1117	2N257	2N268	CTP 1109	CTP 1111	Units
Instantaneous Collector-to-base Voltage (absolute Maximum)	−60	−40	−40	−80	−20	−80	Volts
Junction Temperature (absolute Max.)	85	85	85	85	85	85	°C
Average Total Power Dissipation (with inf. heat sink @ 25°C)	25	30	25	25	25	25	Watts
Average Total Power Dissipation (with 36 sq. in. heat sink @ 25°C)	15	18	15	15	15	15	Watts
Typical Power Gain	a	33[b]	33[c]	31[c]	30[d]	26[c]	db
Frequency Cutoff	5	6	7	6	6	4	Kc/s

a Large Signal D.C. Current Gain = 12 to 40 at Ic = 2.0 amps.
b Vcc = −14V; Ic = 750ma; R_L = 17Ω (choke coupled); R_g = 10Ω
c Vcc = −14V; Ic = 420ma; R_L = 30Ω (choke coupled); R_g = 10Ω
d Vcc = −7V; Ic = 420ma; R_L = 15Ω (choke coupled); R_g = 10Ω

CLEVITE TRANSISTOR

CLEVITE

TRANSISTOR PRODUCTS
241 Crescent St., Waltham 54, Mass. TWinbrook 4-9330

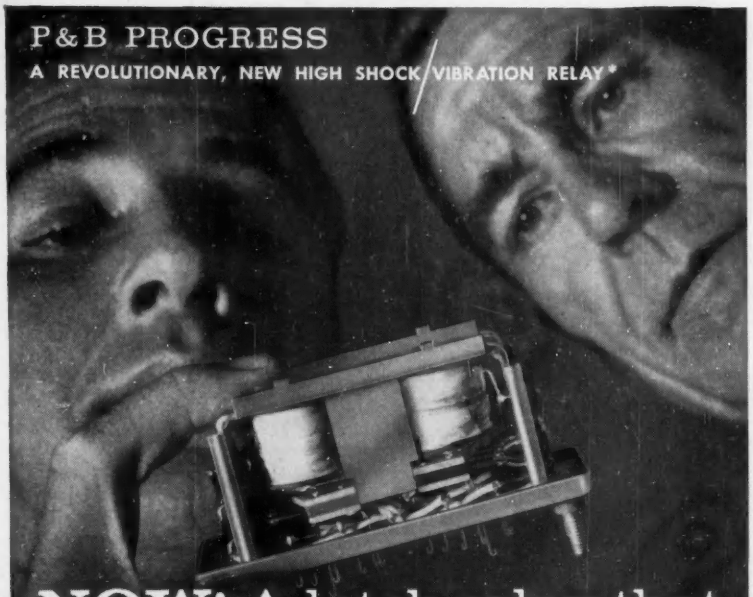
A Division of Clevite Corporation

Brush Electronics Co. | Cleveland Graphite Bronze Co. | Clevite Harris Products Inc. | Clevite Ltd. | Clevite Research Center

German Semiconductor Plant: Intermetall G.m.b.H.-Dusseldorf.

P&B PROGRESS

A REVOLUTIONARY, NEW HIGH SHOCK/VIBRATION RELAY*



NOW! A latch relay that withstands 100g shock, 30g vibration to 2000 cps.

ONLY 2.0 WATTS AT NOMINAL VOLTAGE FOR 12 MILLISECONDS EFFECTS ARMATURE TRANSFER

The secret of the KG's dramatically high resistance to shock and vibration is a permanent magnet which locks the armature into position.

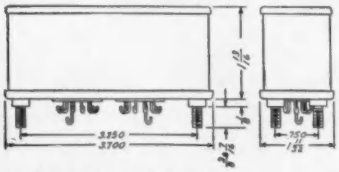
Tests show the contacts will open for no more than 80 microseconds during 100g shock.

Armature transfer from one set of the 6PDT contacts to another can be made in approximately 12 milliseconds with only 2.0 watts at nominal voltage.

Write or wire today for complete technical data.

*KG Relay Patent Pending

STAR SERIES KG RELAY ENGINEERING RESUMÉ



DESIGNATION: KG23DBH

GENERAL: Insulating Materials: Teflon, glass and ceramic.
Insulation Resistance: 100 megohms min.
Breakdown Voltage: 500 V. RMS.
Shock: 100g where contact openings less than 80 microseconds may be permitted.
Vibration: 30g 5 to 2000 cycles.
Ambient Temperature: —65°C to +125°C.

Weight: 13 ozs.
Pull-in-Speed: 12 MS using 310 ohm coil at 24 V. DC. (25°C).
Terminals: Two 11 pin multiple solder headers with hook ends for 3.20/AWG wires.
Enclosures: Hermetically sealed only.
Dimensions: 1-11/32 x 3.700 x .1-13/16 (See drawing for width, etc.)

CONTACTS: Arrangements: 6 pole double throw.
Load: Dry circuit to 3 amps, 115 V. AC, resistive. 5 amps, 28 V. DC, resistive.

COIL: Power: 2.0 watts at Nominal Voltage.
Duty: Either coil may be left energized without damage to the relay.
Insulation: Teflon tape.

MOUNTINGS: Four ⅜ inch #8-32 studs on 3¼ x ¾ inch centers.

P&B STANDARD RELAYS ARE AVAILABLE AT YOUR LOCAL ELECTRONIC, ELECTRICAL AND REFRIGERATION DISTRIBUTORS

Potter & Brumfield, inc.

PRINCETON, INDIANA Subsidiary of AMERICAN MACHINE & FOUNDRY COMPANY

NEW PRODUCTS

detent mechanism are mounted between two Ledex rotary solenoids whose armature plates face each other. The clutch rotates with one or the other of the energized armatures to which it has been magnetically attracted, causing shaft rotation. Deenergizing the solenoid returns the armature to its original position, while the clutch and shaft are held in their new position by the detent action. Life expectancy is claimed to be 2 million steps in either direction; angular increment per pulse in either direction is 36 deg at a maximum pulsing rate of 15 per sec. Temperature range is minus 55 deg C to 120 deg C. —G. H. Leland, Inc., Dayton, O.

Circle No. 64 on reply card

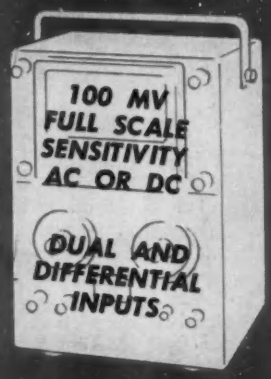
FINAL CONTROL ELEMENTS

LOW TIME CONSTANT

Here is a new integrated electrohydraulic servovalve-actuator combination that requires no electrical feedback or electronic amplifiers to accurately position the output member. An extremely low time constant and essentially infinite resolution are inherent in this mechanical feedback system. The high performance of the servo system permits full actuator stroke with electrical error input as low as 0.06 watts. Extremely compact, the unit uses a basic dry-coil torquemotor servovalve, and operates at pressures from 300 to 3,000 psi with jet fuel, MIL 5606 hydraulic fluid, and other similar liquids.—Hydraulic Research & Mfg. Co., Burbank, Calif.

Circle No. 65 on reply card

New Du MONT TYPE 405 VTVM



Now there's no need to weigh feature against feature when it comes to vacuum tube voltmeters — the new Du Mont 405 has everything!

The 405 is the first VTVM to combine **100 millivolt** full scale sensitivity, either **AC or DC,** with **dual and differential inputs.** Besides, it features DC performance from **2 millivolts to 1000 volts** with **120 megohm input.** It doesn't stop there, for it also offers highly accurate AC performance from **below 50 cps** up into the **UHF range.** As an **ohmmeter,** the Type 405 is calibrated from **0 to 500 megohms,** in eight ranges.

Another in the outstanding Du Mont 400 Series, the 405 is "human engineered" for ease and convenience of operation, reliability, and precision. Its rugged construction is backed by the exclusive Du Mont 5-year guarantee offered with all instruments of the 400 Series.

Price **$265.00**

Slightly higher in 50-cycle areas.

Write for complete details

FEATURING

- **ACCURACY:** 2%.
- **SCALE:** Illuminated 4" mirror-backed scale for accurate readings.
- **STABILITY:** Very low drift. Less than ± 3 millivolts on any range.
- **VERSATILITY:** Designed for safe off-ground operation up to 1000 volts DC.
- **REGULATED:** Regulated DC and filament supply.
- **AMPLIFIER OUTPUT:** Amplifier output available with power gain over 60 db.
- **SIZE:** Compact, weighs only 12 pounds.
- **PROBE STORAGE:** Built-in probe storage compartment.

DU MONT®

One of the 400 Series

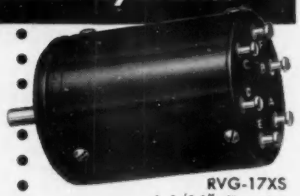
Technical Sales Department, ALLEN B. DU MONT LABORATORIES, INC., Clifton, N. J.

NOW!

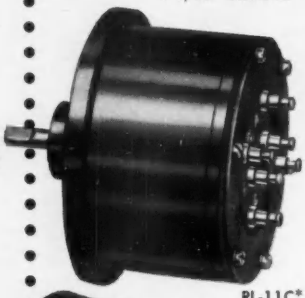
SAVE WEIGHT, SPACE and COST

in computing and control systems

GAMEWELL
Sinusoidal Precision Potentiometers



RVG-17XS
1 1/16" diameter



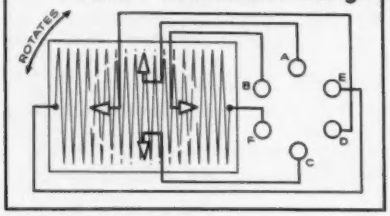
RL-11C*
2 5/16" diameter

RL-14MS*
4 3/8" diameter

A specially designed oblong resistance element rotating under 4 wipers generates precision sine and cosine voltages, proportional to the sine or cosine of the shaft rotation angle. Functions produced to an inherent accuracy and smoothness unobtainable by other resistive methods. Can replace eccentric gears, cams and complicated mechanisms in computing, analyzing, navigational and control systems.

Send for technical data! Functional detail, dimensions and specifications will help you apply.

Sketch of Gamewell Sine-Cosine Precision Potentiometer Design



Can be used as a 1 brush device, 2 brush (sine) and 2 brush (cosine) device, or in combinations — to produce various sinusoidal variations. E–F = V_{in}, A–C & B–D = V_o.

*Described in full in Radiation Laboratory Handbook, Vol. 17.

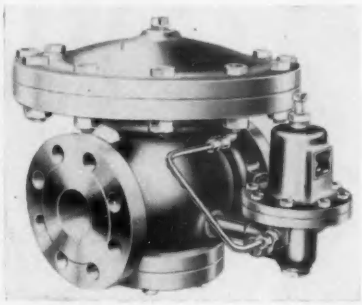
THE GAMEWELL COMPANY
Newton Upper Falls 64, Mass.

GAMEWELL®

PRECISION POTENTIOMETER DIVISION

GA7-13

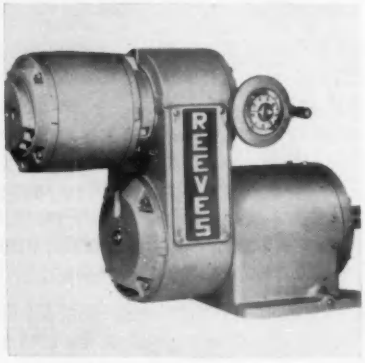
NEW PRODUCTS



SELF-OPERATED

Type 92B, an improved version of a time-tested pilot-operated reducing valve for steam service, obtains its pilot operating medium directly from the inlet. This is a desirable feature in applications where operating mediums such as air or gas are not available or where use of such mediums is not practical. Maker claims the new design eliminates clogged orifices, sticky valves, and diaphragm rupture, and simplifies maintenance.—Fisher Governor Co., Marshalltown, Iowa.

Circle No. 66 on reply card



TWO NEW DRIVES

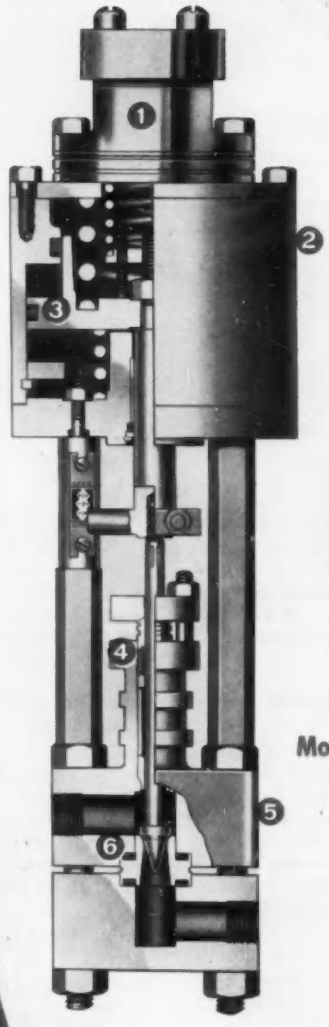
Two new precision-built, Vari-Speed Motodrives, sizes 200 to 300, are available in either "C"-flow or "Z"-flow styles (latter shown). The units are specially suited for 1-to-5-hp applications and incorporate the following improvements: new disc assemblies for wider output speed ranges, "close-grooving" lubrication for easier disc motion, and a new lubricating system for the motor and variable shaft bearings. Complete line now covers ¼ to 40 hp.—Reeves Pulley Co., Columbus, Ind.

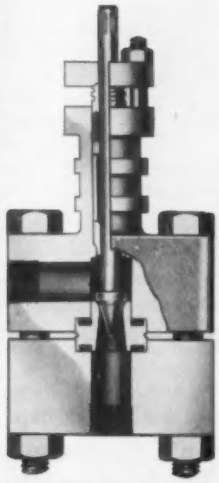
Circle No. 67 on reply card

Split second action ...small flow control ...at 6,000 psi

New achievement by Annin in high pressure control and precise valve response for Research–Development–Process applications

Annin's new Model 9460, designed for working pressures to 6,000 psi, provides research, pilot plant and process control engineers with an extremely responsive small flow control valve suitable for low capacity systems. The operator will fully stroke in either direction in 0.75 seconds or less. New design features include: ❶ integral positioner, open-on-air-failure or close-on-air-failure action; ❷ Annin's 600 Series Domotor operator; ❸ differential area piston, eliminating need for loading regulator; ❹ universal stuffing box for −400°F to 750°F; ❺ offset globe or angle body design; ❻ valve plug stem and seat ring common to both globe and angle bodies. For reliable fluid control and flexibility of application Annin offers the *best source* for solving any small flow control problem.



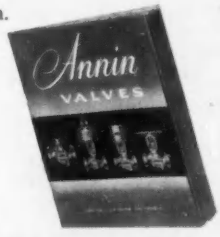


Model 9461 *angle body*

Angle bodies are available with body sections rotatable in 90°increments for piping convenience.

YOURS FOR THE ASKING—

Complete information and specifications are contained in Bulletin No. 9400. Write for your copy today.



ANNIN *Control* **VALVES**

THE ANNIN COMPANY
DIVISION OF THE ANNIN CORPORATION
6570 Telegraph Road, Los Angeles 22, California

Continued from page 24

Another L&N solution to the area regulating problem

FP&L's H. W. Page and O. H. Bridges discuss new control center layout.

and, in 1951, Page predicted** a type of computer which closely matches the one now being built for his system. For example, he foresaw today's function generator which enables the computer to digest — and remember—the cost characteristics of each unit. The prediction went so far as to visualize the physical outline of some of the major computer-control components.

Building Block Approach

As a result, FP&L's planned approach to computer-control included installation of its present Area Control in 1955. It was a nicely planned move, for the control arrangement was well suited to future requirements—including the integration of an analog computer.

All Major Generating Sources Now Under Control

With its present Area Control, FP&L has all eight major plants—plus four ties with the Interconnected System — under automatic control. The control has sufficient flexibility not only to make lowest cost of generation possible, but also to permit automatic operation during the morning pick up as well as during periods of adverse conditions when it may be necessary to depart from economic loading to meet customer load demand.

Adequate Feedback

A big reason for success of the control is the positive feedback of all significant control intelligence, including unit and station response to control signals. With regulating units moving in unison along their respective incremental cost curves, "hunting" among units and stations is eliminated—and with it, the unnecessary generation changes (including resultant dollar loss) which could occur if units were to respond to anything other than the basic (area) requirement.

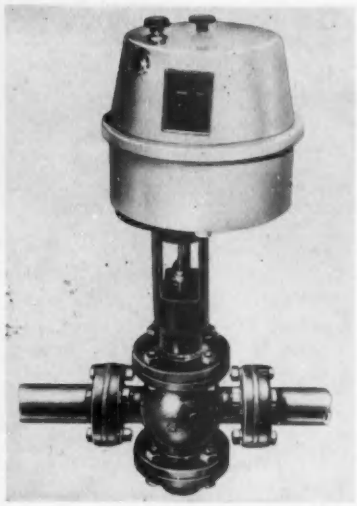
The Operating Man: Guide to Lower Costs

In light of the work now in progress in Miami and other control centers around the country, we of Leeds & Northrup want to suggest that the operating engineers on your own system are your best guide to more economical, more reliable control. We find that when they review all the facts, they specify control by control specialists.

Let us send you the facts on some 40 typical Area Control installations as described by the utility company engineers who operate them. Just write to Leeds & Northrup Company, 4918 Stenton Avenue, Philadelphia 44, Pa.

***From a talk delivered to the Southeastern Electric Exchange, March 29, 1951. "Loading of Power Plants for Maximum System Economy."*

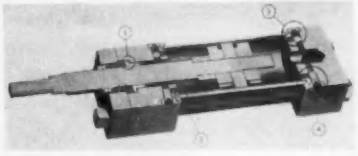
NEW PRODUCTS



NEW VALVE OPERATOR

Here is a self-contained electro-hydraulic valve actuator that will operate equally well on signals supplied by commercially available controllers, remote positioning devices, or directly from the measuring element. It is designed for valves with from ½-to-1½-in. full stroke and requiring less than 200 lb thrust, and comes with standard signal ranges of from 1 to 5, or from 4 to 8 ma dc. An internal rectifier is supplied for ac signals.—Askania Regulator Co., Chicago, Ill.

Circle No. 68 on reply card



TEFLON-SEALED

Four design changes have resulted in an all-Teflon sealed cylinder with universal resistance to fluids. Pressure ratings on existing lines can be boosted up and an entirely new line of medium-to-high pressure cylinders can be introduced. The design changes making this possible include: a tube end seal of Teflon plastic, a rod bushing of the same material replacing conventional "0"-rings, a radically new cushion adjusting screw, and a redesigned ball check.—Miller Fluid Power Div. of Flick-Reedy Corp., Melrose Park, Ill.

Circle No. 69 on reply card

Associate Engineer Donald A. Patterson demonstrates a problem in pluggable unit layout.

Field Engineering Instructor Joseph Rechloff explains basic display console functions at IBM, Kingston, N. Y.

Associate Engineer Robert M. Blake points out a feature of an advanced magnetic tape circuit development.

You'll find a new challenge **DEVELOPING** the world's **largest computers** at

IBM Kingston

Staff Engineer Michael S. Zucker and associates plan electronic digital computer systems.

The design and development of SAGE (Semi-Automatic Ground Environment) computers, part of our nation's radar defense system, offer stimulating new challenges to creative engineers at IBM Kingston.

Projects currently in process include: Digital and analog systems . . . advanced circuitry . . . electronic packaging . . . communications engineering . . . simulation studies . . . air traffic control . . . automation.

If you are an electrical or mechanical engineer, a mathematician or a physicist—and want to do development work—you owe it to yourself to investigate the exciting possibilities that SAGE computers offer you at IBM Kingston.

Computer Student Stanley J. Ostrowski studies wave forms in the IBM Computer Engineering School laboratory.

FOR DETAILS,
just write, outlining background and interests, to:
Mr. R. A. Whitehorne, Dept. 2609
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International Business Machines Corp.
590 Madison Avenue, New York 22, N. Y.

IBM MILITARY PRODUCTS

DATA PROCESSING
ELECTRIC TYPEWRITERS
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SPECIAL ENGINEERING PRODUCTS
SUPPLIES
TIME EQUIPMENT

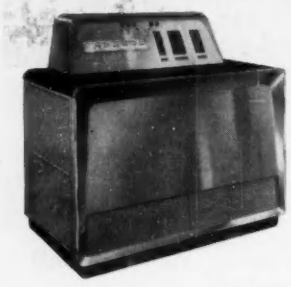
Plants and laboratories: Endicott, Kingston, Owego, Poughkeepsie, N. Y.; Lexington, Ky.; Rochester, Minn.; San Jose, Calif.

Take a number from one to one hundred!

BJ Electronics' new S-100 DIGITAL DATA PROCESSING SYSTEM samples 1 to 100 Transducers at rates up to 100 per second.

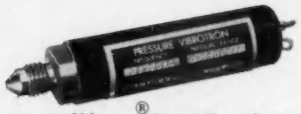
Precise, instant measurement of the variables of pressure, temperature and other inputs are provided to S-100 by as many as 100 miniature Vibroton Digital Transducers. Analog-to-digital conversion inaccuracies are eliminated by these vibrating-wire sensing devices. Measurement is signaled in terms of frequency, delivering direct-digital information sequentially or *on demand* to S-100 at sampling rates up to 100 per second.

This information is processed against programmed storage register data and routed through format control to system outputs for tabulations, visual readout, punched cards, tape or other output media. Output provisions for process monitoring and control may also be incorporated.



S-100 System

See S-100 in action!
ISA SHOW
Cleveland, Ohio
September 9-17, 1957
Booth No. 118



Vibroton® Digital Transducer

Write for Technical Bulletin 58-112

Qualified engineers are assured interesting, rewarding careers at this new Borg-Warner electronic facility. Inquire today of O. C. Bowers, Chief Engineer.

BJ ELECTRONICS

Reliability you can count upon

BORG-WARNER CORPORATION

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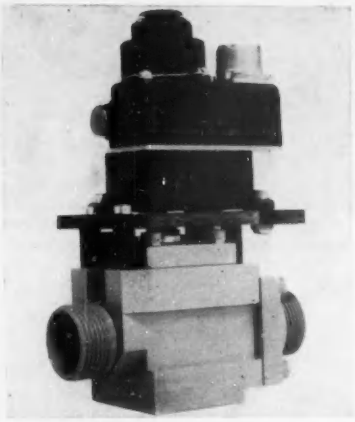
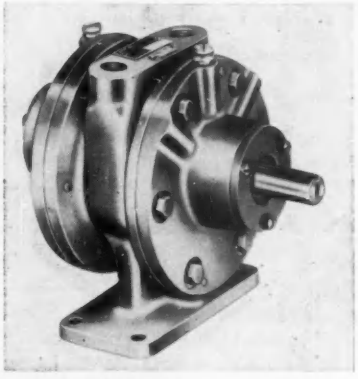
NEW PRODUCTS



PRESSURES TO 3,000 PSI

A new series of high performance shutoff valves, for air and ground applications that require reliable, bubble-tight flow control of extremely low-temperature (minus 320 deg F) and high-pressure (3,000 psi) media, handle helium, oxygen, nitrogen, and air in either the gaseous or liquid states. A floating ball-seat valve arrangement assures long, trouble-free life. A smooth, unobstructed flow path results in minimum pressure drop at all rates of flow. Current is automatically shut off at the end of each valve cycle. In either the open or closed position, the valve is locked in place by a Geneva-lock mechanism. — Hydromatics, Inc., Cedar Grove, N. J.

Circle No. 70 on reply card



NEW AIR MOTOR

The Model 6 AM air motor for original equipment or plant use in the ¼-to-2-hp range features reversible rotation for machine-tool positioning, powering screw jacks, and similar ap-

Portion of Eclipse-Pioneer's synchro calibration and test facility.

WHY IT PAYS TO SHOP AT THE BENDIX "SUPERMARKET"

— NATION'S LARGEST PRODUCER OF SYNCHROS

SHAFT POSITION-TO-DIGITAL CONVERTERS

Eclipse-Pioneer Coded Commutator type shaft position-to-digital converters are miniature devices for converting Analog information to Binary Digital form. Designed for Digital control systems, data processing equipment, telemetering applications, or computers. Especially suited to air-borne use.

Specifications:

	Model GS-1-A1	Model GS-2-A1
Type output	8 digit gray (Reflected Binary Code)	7 digit Natural Binary Code (double brush)
Shaft resolution	1 part in 256	1 part in 128
Current rating	.015 amps. (max.) per digit with non-inductive loading	.015 amps. (max.) per digit with non-inductive loading
Shaft speed	Max. continuous input of 150 revs. per minute	Max. continuous input of 150 revs. per minute
Input torque	0.2 ounce-inch (max.)	0.4 ounce-inch (max.)
Diameter of unit	15/16 inch	15/16 inch

In buying precision synchros, doesn't it make a lot of sense to insist on getting exactly what you want, when you want it—and at minimum cost?

Best way to be *sure* you get all three is to depend on the Bendix "Supermarket".

Our mass synchro production facilities . . . the nation's largest . . . are constantly turning out just about all types of synchros imaginable. This means we can offer you immediate delivery of most synchro types—and minimum cost on all synchro types, even for small quantity orders.

You can depend on the quality of Bendix synchros, too. They will equal . . . or exceed . . . the accuracy of any other synchros made today. Sound reasons why you'll be ahead to rely on the experience and mass-production facilities of *Bendix*.

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Eclipse-Pioneer Division

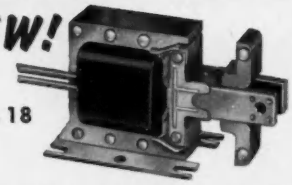
Teterboro, N. J.

Bendix
AVIATION CORPORATION

3 new GUARDIAN Solenoids

with POWER and a Stroke that add new "lift" to your product!

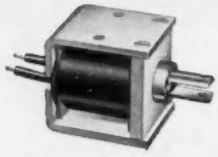
NEW! No. 18



with PERMASEAL Coil

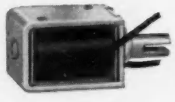
Preferred where moisture conditions prevail. Coil winding, completely encapsulated in PERMASEAL thermosetting epoxy, resists water, humidity, oils, salt air, acid and alkaline solutions, ether, alcohol, hydraulics and other fluids. High dielectric strength, resistance to abrasion and thermal or mechanical shock enable it to operate at top efficiency.

NEW! HEAVY DUTY No. 2



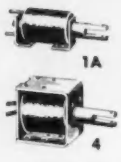
This new special version of Guardian's standard No. 2 Solenoid provides extra power and longer life yet utilizes the same space. Available in A.C. or D.C., for intermittent or continuous duty. Stroke adjustable from 1/32" to 3/4"—lift more than 60 oz. Unit has surpassed 15 million continuous operations at peak operating efficiency.

NEW! MIGHTY MIDGET No. 22

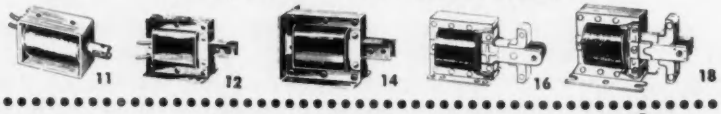


Tiny but powerful, this new Guardian Midget Solenoid packs a decisive punch. Strokes range from 1/32" to 5/16" and it lifts over 24 oz. Size 3/4" x 3/4" x 1 1/8" is ideal when space is at a premium. Available in D.C. only, for intermittent or continuous duty applications.

Select Your Solenoids from GUARDIAN'S COMPLETE LINE ...Proved for Superior Performance!



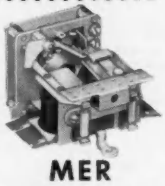
Many Guardian solenoids are available with Guardian PERMASEAL encapsulated coils. Most standard units are sufficiently flexible in design to meet "special" requirements and thereby eliminate costly pretooling. Adjustable strokes up to 2 inches; pull or lift up to 20 pounds. All D.C. units available for 400 cycle operation. Write for Bulletin SOL-8.



Large selections of Guardian relays, solenoids and steppers are carried in stock by franchised distributors in the U.S. and Canada. Write for name of nearby distributor and Bull. SD-11.

GUARDIAN STEPPERS

Get Guardian's free Bulletin P-84. Gives complete operating data on sequence selecting, latching, automatic homing, remote homing, pulsing, electrical reset, slave and master sets, continuous rotation, add/subtract.



MER

GUARDIAN ELECTRIC

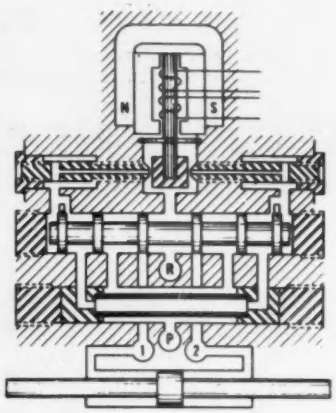
1623-K W. WALNUT STREET CHICAGO 12, ILLINOIS

"Everything Under Control"

NEW PRODUCTS

plications. Any four-way operating valve for pressures below 100 psi may be inserted in the air supply line for instantly reversible motor control. Motor ports fit standard 3/8-in. pipe. Units weigh about 17 lb, are explosion-proof, and vary in speed from 300 to 2,000 rpm on air-line pressures of 30 to 90 psi.—Gast Mfg. Co., Benton Harbor, Mich.

Circle No. 71 on reply card



WELL BALANCED

A new series of two-stage electrohydraulic flow-control valves represents a marked departure from previous designs. The valves use a closed-loop hydraulic control circuit to position the output stage, and are of a balanced push-pull construction. No springs are used. The valves have a minimum of moving parts and a large capacity filter to protect the control stage, and are of the "dry-coil" design. Accompanying schematic indicates the internal arrangement and the electromechanical transducer.—Cadillac Gage Co., Detroit, Mich.

Circle No. 72 on reply card

RUGGED CONSTRUCTION

A new line of 3-way solenoid valves, Series 500, is designed to provide low-cost automatic temperature control for air-conditioning systems. Features include durable construction, good corrosion resistance, low pressure drop, quiet operation, long life, and low cost. All connections are 1/2 in. NPT.

Jackes-Evans Mfg. Co., St. Louis, Mo.

Circle No. 73 on reply card

Don't Worry
about a thing!
The New Sensitive Research
CONTACT METER
will control it *AUTOMATICALLY*
to an accuracy of .25%.

CONTACT MAKING PANEL INSTRUMENTS
for the Automatic Inspection or Control Between Electrical Minimum & Maximum Limits.

Sensitive Research Contact Making Edgewise Panel Instruments provide the means for the electrical sensing of "preset" values of Voltage, Current, Watts, Micromhos and any other quantity that can be indicated electrically. More than just Contact Making Instruments, they are Reference Standards, modified with either upper or lower contacts or both, and furnished with either one or two relay systems. Sensitive Research Contact Meters have Stability, Long Life and Traditional Dependability, which means you ***'DON'T HAVE TO WORRY ABOUT A THING.'***

- Available for AC, DC or both.
- Accuracies to .25%.
- Automatic or manual resets.
- 7" or 5" hand drawn mirrored scales.
- Contact resolution to .1%.
- Contacts continually variable over 90% of the instruments scale.
- Ultra high sensitivities.

WRITE DEP'T K FOR ADDITIONAL INFORMATION.

Represented by the Heiman Co. in Minn., Iowa, N. & S. Dakota.

SENSITIVE RESEARCH INSTRUMENT CORPORATION

NEW ROCHELLE, N. Y.

ELECTRICAL INSTRUMENTS OF PRECISION SINCE 1927

S
Symbol of Quality

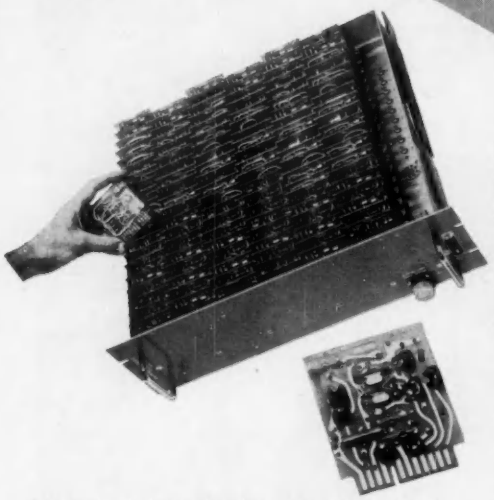
NEW EECO

-40° C to +100° C

Silicon

TRANSISTOR PLUG-INS

for extremely reliable ground and airborne equipment



This is the first **complete line** of transistorized systems components offering hermetically sealed **silicon** semiconductors and components.

Check these features:

- Operate reliably in ambient temperature range of −40°C to +100°C.
- Smaller, more compact (mounted on 2-7/8" x 2-9/16" x 1/16"-thick epoxyglass); still incorporating more components.
- Power supply requirements ±20 Volts.
- Plug into any standard 12-contact etched-circuit connector.
- All plug-in contacts rhodium-plated for long life and trouble-free service.
- Complete supply of compatible systems hardware.

CIRCUITS: The complete line of EECO **Silicon** Transistor Plug-in circuits includes:

FLIP-FLOPS	**EMITTER FOLLOWERS**
ONE SHOTS	**SQUARING CIRCUITS**
NEON DRIVERS	**LINEAR AMPLIFIERS**
RESET GENERATORS	**BLOCKING OSCILLATORS**
DIODE LOGICS	**and many others.**

NEW EECO RUGGEDIZED STANDARD-SERIES PLUG-INS

The full line of tested and proven circuits available in EECO's Standard-Series Plug-ins has been ruggedized for even greater reliability and more efficient performance.

Each unit now incorporates the IERC Shield to:

- Protect tube from vibration and shock.
- Dissipate heat more effectively.
- Ensure longer tube life with cooler, more efficient operation.
- Provide even greater electrical shielding.

New mechanical construction and design assures full protection to critical components against stress or tension.

All ruggedized units are compatible with EECO Standard-Series hardware and EECO Systems Development Racks.

NEW CIRCUITS include High-Speed Flip-Flops, Oscillators, etc., in both Computer-Series and Standard-Series Plug-ins . . . plus other systems building blocks: D-C Chopper Stabilized Amplifiers, Power Supplies and Compatible Accessories, Systems Development Racks, Systems Components. Detailed information available in Catalog No. 856-A.

AVAILABLE SOON: New EECO Germanium Transistor Plug-ins. These EECO units will comprise a complete line of transistorized systems components, including a full complement of circuits (One Shots, Flip-Flops, Linear Amplifiers, Pulse Amplifiers, "And" Gates, "Or" Gates, and many others) as well as compatible systems hardware.

ENGINEERED ELECTRONICS COMPANY

a subsidiary of

Electronic Engineering Company of California

506 EAST FIRST STREET · SANTA ANA, CALIFORNIA

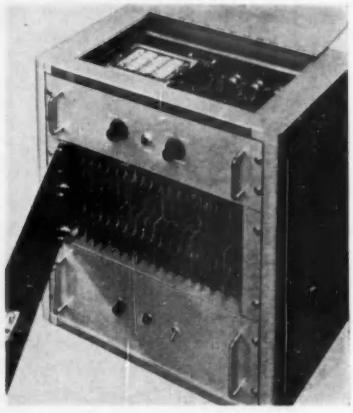
NEW PRODUCTS

SHOCK-FREE CONTROL

The 1701 Series hydraulic control valves are said to provide smooth and positive directional control in hydraulic pressure systems. In operation, a cylindrical screw-type slide plunger is actuated through a 28-vdc motor-driven two-stage gear train. Basic design provides two-way control with ½-in. slide travel. One-piece body eliminates leaks.—Lyndon Aircraft, Inc., Newark, N. J.

Circle No. 74 on reply card

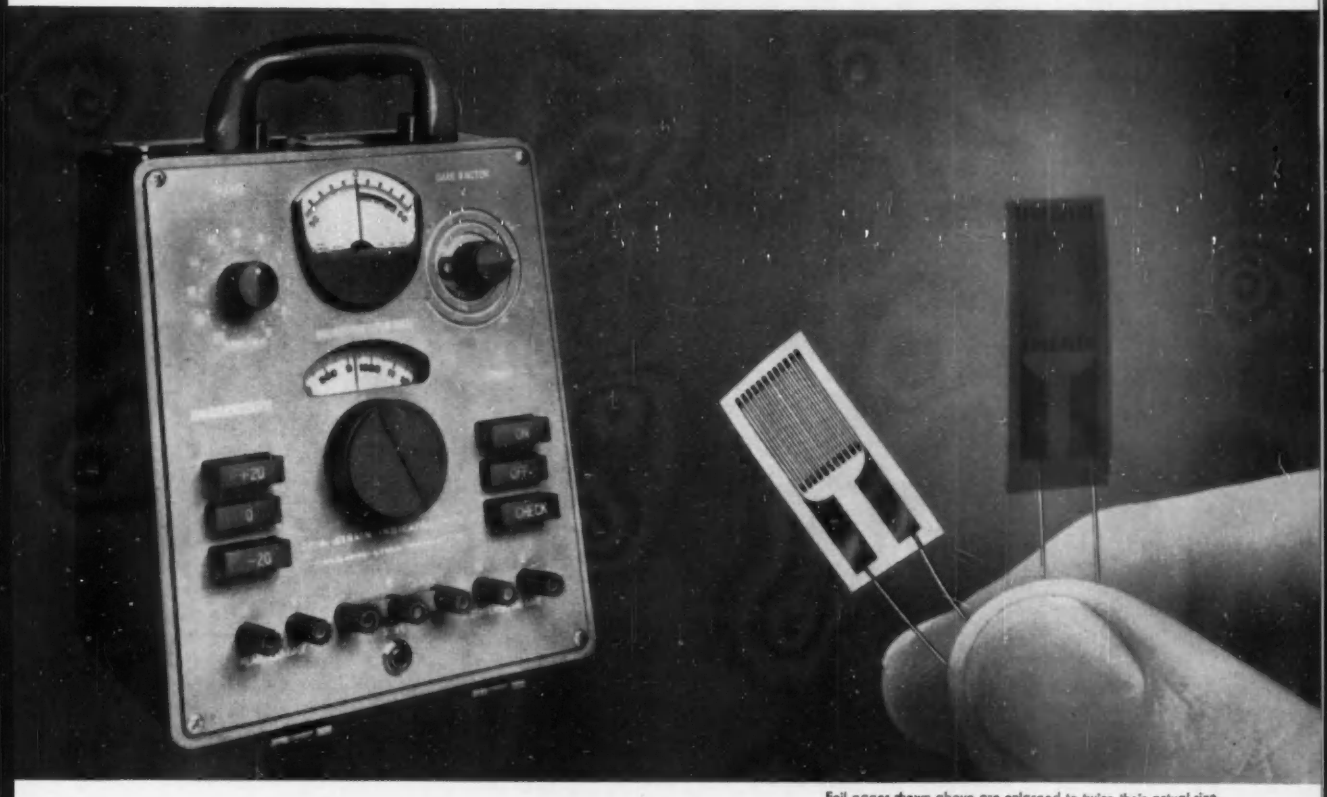
COMPONENT PARTS



BUFFER STORAGE

This new Type 1092-BQ-8 Buffer Storage Unit, featuring coincident current and magnetic core, can serve as a temporary store, buffer, or delay unit in data processing, computing, and automation systems. Each of the 1,092 characters has a capacity of eight binary digits in length. Unit is com-

Newest strain-measuring equipment from Baldwin



Foil gages shown above are enlarged to twice their actual size.

NEW SR-4® strain indicator and NEW SR-4 bonded foil strain gages

Type N SR-4 Strain Indicator

This new, improved strain indicator features printed circuits and transistors, weighs one-third less than the previous model and has a smaller case. No warmup is required. In intermittent service its batteries last up to five times as long and cost two-thirds less. The legs of the case are positioned to permit tilting for improved readability. For direct readings with full external bridge, no calibration correction is required. Used as a preamplifier with standard cathode ray oscilloscope, it gives visual indication of dynamic strain with better response and in a broader range than the previous model. Frequencies up to 300 cps at amplitudes up to 3500 microinches per in. can be observed without appreciable distortion.

SR-4 Bonded Foil Strain Gages

Two new types of foil gage in ½ in. gage length, 120 ohms resistance, now make many types of stress analysis possible with new accuracy and ease. A Bakelite-bonded gage, Type FAB-2, and a quick-drying paper-and-cement-bonded gage, Type FAP-2, have marked advantages over comparable standard bonded wire strain gages. Hysteresis is now so low as to be negligible for stress analysis. Fatigue life of the paper gage matches that of comparable wire gages—that of the Bakelite gage is longer. Lateral strain sensitivity of both is down by one-half, offering new accuracy in measuring biaxial strains. The quick-drying paper gage is quick and easy to install. The Bakelite gage offers such attractive features as dependable service at 300°F or higher. It is thinner and more flexible than comparable bonded wire gages—requires no preforming for curved surfaces and is thus easier to apply. Its glass fiber filler makes it less sensitive to moisture effects.

Both new foil gages have tinned lead wires, well anchored and easy to connect. Both gages are now stock items for prompt delivery. For more information on this or other Baldwin stress analysis equipment, write to Electronics & Instrumentation Division of B-L-H, Waltham, Mass. Or we will have a representative call on you at your request.

BALDWIN · LIMA · HAMILTON

Electronics & Instrumentation Division

Waltham, Mass.

SR-4® strain gages • Transducers • Testing machines

PHALO
had the Answer

AccuRay® Equipment shown controlling Strip Thickness of Cold Rolled Steel

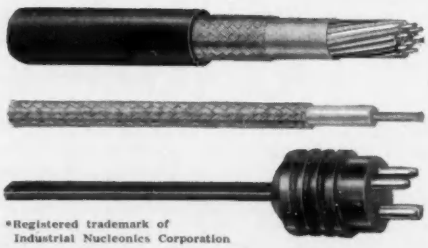
to AccuRay® Cable Demands

Industrial Nucleonics have made process control systems cable talk wherever businessmen meet.

AccuRay® applications like that shown here are doing rugged work in many diverse installations. Phalo cables provided the answer to exacting demands in the interconnection of components of the AccuRay System, as in source detector units to electronic consoles and remote stations.

The AccuRay System really gives cable a test . . . only the finest quality stands the pace.

Call on Phalo with confidence for Instrumentation and Control Interconnection cables. Power Supply Cords, Shielded Custom Molded Plugs and Connectors and Shielded Wire.



Ask For The New PHALO *Catalog just published*

*Registered trademark of Industrial Nucleonics Corporation

PHALO PLASTICS CORPORATION
25-8 Foster Street
WORCESTER, MASSACHUSETTS

NEW PRODUCTS

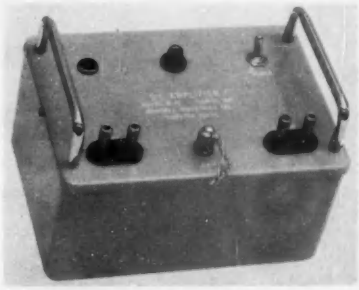
pletely transistorized.—Telemeter Magnetics, Inc., Los Angeles, Calif.

Circle No. 75 on reply card

HOT SYNCHROS

The size 10 synchro transmitter shown above was developed for direct turbojet-engine mounting and has passed tests at 450 deg F for 100 hours and at 350 deg F for 1,000 hours. High accuracies were maintained throughout these tests. The units are housed in stainless steel and are available as transmitters, transformers, differentials, and resolvers.—Clifton Precision Products Co., Inc., Upper Darby, Pa.

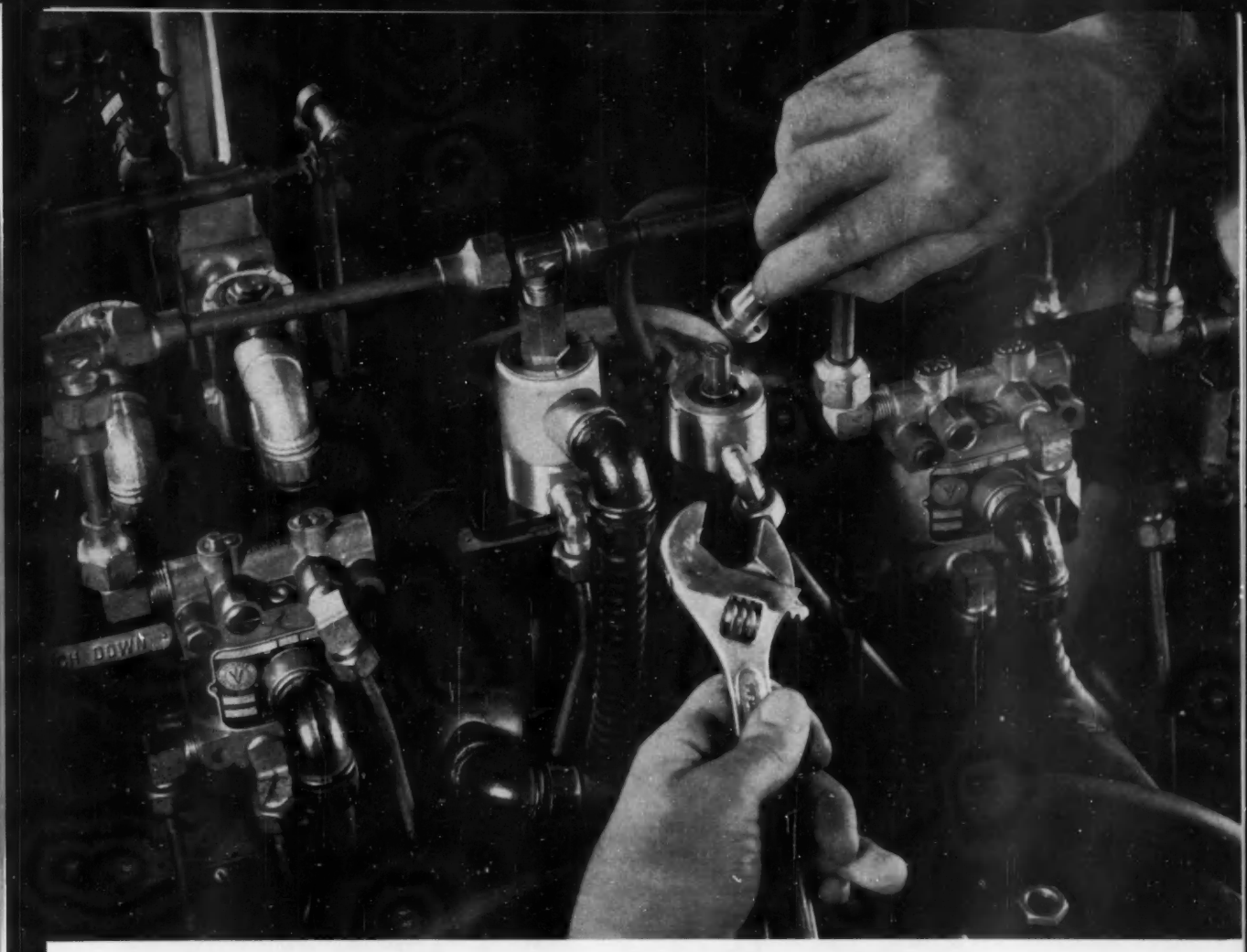
Circle No. 76 on reply card



CHOPPER STABILIZED

Specifically designed for use as a preamplifier in meter-movement recorders, this new dc amplifier features chopper stabilization and sells for $120. A 10-mv input produces a 1.5-volt output across a 1,500-ohm load. Linearity and zero drift are within 1 percent; accuracy is within 2 percent from dc to 2 cps. Unit consumes 14 watts operating on a 115-volt, 60-cps supply. Primary application is lab amplification of thermocouple, strain-gage, thermistor, and photo-cell outputs but it can also perform control and metering jobs.—Mandrel Industries, Inc., Houston, Tex.

Circle No. 77 on reply card



Skinner Solenoid Valves are easier to maintain and service because of their simplified design

The man shown above is cleaning a Skinner Solenoid Valve. He has disassembled it by hand without removing it from the line. Simplicity of design makes this simple maintenance and service feature possible. The design of Skinner valves is such that coils and other parts are interchangeable and easily, quickly replaced. They are readily available, too — reducing the stocking of spare parts to a minimum.

Skinner Solenoid Valves are made of the very finest materials available and contain only two moving parts. Their joints are heli-arc welded on special electronically controlled equipment. Their coils, manufactured to UL standards, will operate for years without burnout. Their positive spring returns eliminate sticking. And they have no packing to wear out and cause leakage.

If you are looking for solenoid valves that will give you longer trouble-free performance, look to Skinner valves. For complete information on Skinner's line of 2-, 3- and 4-way valves, write us or contact a Skinner representative. Write Dept. 349.

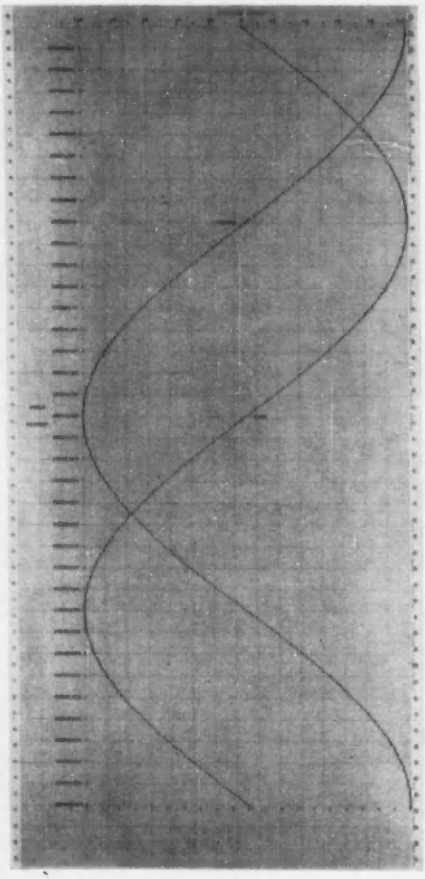
Skinner Solenoid Valves are distributed nationally

SKINNER ELECTRIC VALVES

SKINNER ELECTRIC VALVE DIVISION

NEW BRITAIN
CONNECTICUT
105 EDGEWOOD AVENUE

THE CREST OF QUALITY



This is a greatly-reduced reproduction of sine and cosine curves demonstrating the ability of a standard tabulator to present data in graphical as well as printed form.

"READ-OUT" PROBLEMS?

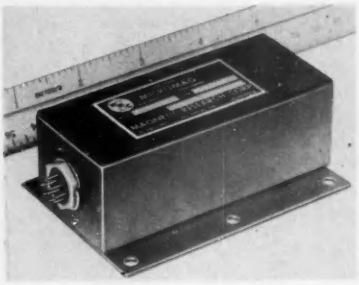
Your computer output, as an example, can be quickly converted to accurate graphical form for immediate reading by tabulating your data on GRAPHIC's specially designed Continuous Grid Paper.

GRAPHIC combines the facilities and experience of five specialized firms to bring you a new, unique service. Whatever your specific needs for plotting paper, special controller charts, high speed printer paper . . . and others . . . GRAPHIC engineers can help you develop them. Send your requirements.

GRAPHIC CONTROLS CORPORATION
189 VAN RENSSELAER ST. BUFFALO 10, N. Y.

combining the facilities of
STAEBLER & BAKER INC. TECHNICAL CHARTS INC.
CLARKSON PRESS INC. AMHERST PRINTING CO., INC.
STAEBLER & BAKER LTD. (Canada)
manufacturing and supply units
TECHNICAL SALES CORPORATION
sales and service unit

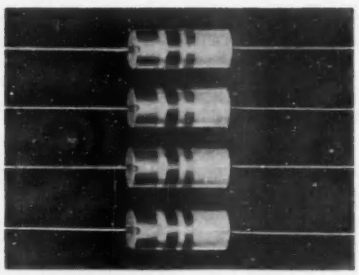
NEW PRODUCTS



TEMP-COMPENSATED

This new magnetic, low-level, dc signal amplifier, designed to operate from a 28-volt aircraft or missile system, features a built-in transistor oscillator which generates its own frequency. This permits operation on a dc source. Designated the Micromag MMO-528, the unit has a voltage gain of 500, producing 5 vdc for a 10 mvdc input. Applications include the amplification of signals from thermocouples, strain gages, and similar low-level transducers. Temperature-compensated for gain stability, the unit has virtually no zero drift.—Magnetic Research Corp., Hawthorne, Calif.

Circle No. 78 on reply card



POTTED CHOKES

A family of epoxy encapsulated chokes is now available from stock. The 13 units, following preferred values, range from 1.1 to 120 microhenries. All are $\frac{1}{8}$ in. in diam by $\frac{3}{4}$ in. long with axial pigtail leads, color-coded for easy identification, and constructed for maximum ruggedness and resistance to moisture and other environmental extremes.—Cambridge Thermionic Corp., Cambridge, Mass.

Circle No. 79 on reply card

SILICON TRIODES

Four new high-temperature, high-frequency silicon transistors are now avail-

SIZE 23

Norden-Ketay presents a superior new synchro . . .

3SYN

THE 3 FUNCTION, 3 MINUTE QUADRATURE BAR SYNCHRO

3SYN as a TORQUE TRANSMITTER

- Twice the torque gradient (0.25 oz-in) of standard mil synchros (0.13) drives a bigger load, or the same load more accurately.
- More than twice the electrical accuracy (3′) of mil synchros (8′).

3SYN as a CONTROL TRANSMITTER

- Better regulation with less input current improves efficiency, drives more transformers.
- 3-minute accuracy surpasses mil synchro performance (8′).

3SYN as a TORQUE RECEIVER

- Twice the receiver accuracy (±½° error) compared with standard mil synchro (±1° error).
- One-half the damping time (1 sec) compared with mil synchro (2 secs).

3-IN-1 VERSATILITY: TORQUE TRANSMITTER TORQUE RECEIVER • CONTROL TRANSMITTER

FUNCTION	UNITS	3SYN	STANDARD MIL SYNCHROS
NKC TYPE DESIGNATION		113CF2A	113F2B/113C2A
Number of Phases } STATOR / ROTOR		3 / 1	3 / 1
EXCITATION PHASE		Rotor	Rotor
FREQUENCY	cps	400*	400
VOLTAGE RATING	volts	115/90	115/90
Maximum Input } CURRENT / POWER	amps / watts	0.92 / 7.5	1.21 / 9.4
INPUT IMPEDANCE	ohms	138/86.4°	105/86.6°
Maximum Null Volts } TOTAL / FUND.	mv / mv	100 / 50	100 / 75
DC Resistance at 20°C } STATOR / ROTOR	ohms / ohms	3.93 / 3.04	5.86 / 2.59
MOMENT OF INERTIA	oz-in²	0.45	0.43
FRICTION TORQUE AT 20°C MAXIMUM	oz-in	0.1	0.1
ELECTRICAL ERROR, MAXIMUM	minutes	±3′	±8′
RECEIVER ERROR, MAXIMUM	degrees	0.5	1
TORQUE GRADIENT, MINIMUM	oz-in/deg	0.25	0.13
DAMPING TIME, MAXIMUM	sec.	1	2
OPERATING TEMP. RANGE	°C	−55 to +55 †	−55 to +55
WEIGHT	oz.	21	21
MILITARY DESIGNATION			23TR4a/23TX4a

* Although this synchro is rated at 400 cps, 3SYNs are available to your order to operate at any frequency from 400 cycles to 10,000 cycles.

† *The normal temperature range of −55°C to +55°C can be extended to 140°C on special order.*

PLUS

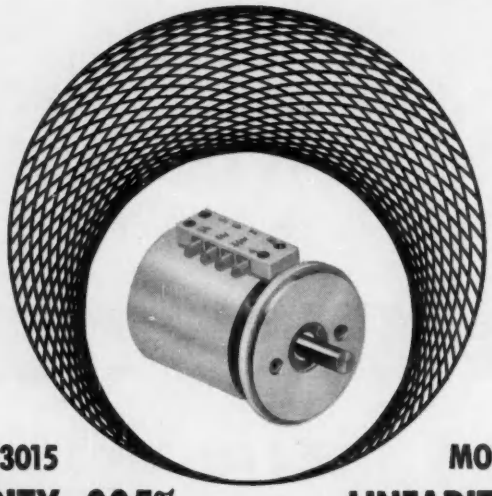
3SYN minimizes problem of 'spares', since it is interchangeable with mil torque transmitters, control transmitters, and torque receivers. Moreover, 3SYN does not merely equal, but *excels* the critical ratings of standard mil synchros in each of those three functions.

· extending man's capabilities ·

NORDEN KETAY

For full data and application engineering on the 3SYN synchro, write to Norden-Ketay Corporation, Western Division, 13210 Crenshaw Blvd., Gardena, Calif.

Sales Offices: Stamford Conn. | Chicago Washington, D.C. | Dayton, Ohio | Los Angeles



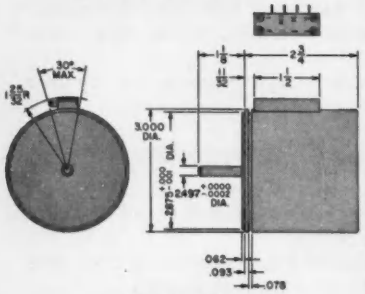
MODEL J3015
LINEARITY .005%

MODEL F1810
LINEARITY .01%

HIGH PRECISION POTENTIOMETERS

IMMEDIATELY AVAILABLE IN PRODUCTION QUANTITIES
SAMPLES SHIPPED IN 48 HOURS

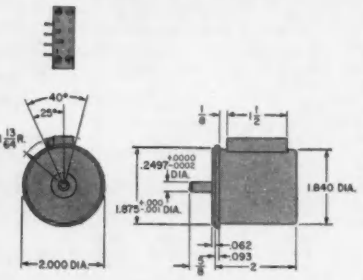
15 TURN – 3 IN. DIA.



MODEL J3015

RESISTANCE RANGE	2K TO 150 K
LINEARITY (STANDARD)	.05% TO .01%
LINEARITY (BEST)	.005% ABOVE 4 K

10 TURN – 1.8 IN. DIA.



MODEL F1810

RESISTANCE RANGE	1 K TO 50 K
LINEARITY (STANDARD)	.05% TO .02%
LINEARITY (BEST)	.01% ABOVE 2K

Now you can design your circuits with Analogue Controls Potentiometers with the assurance that they will be available when you need them!

Complete mechanical and electrical specifications of all our potentiometers are available. Write for Catalog P103 today.

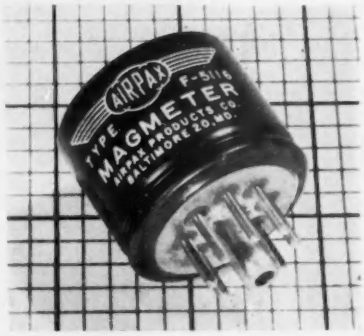
POTENTIOMETERS MEET THE REQUIREMENTS OF NAS-710

Analogue Controls, Inc.
39 ROSELLE STREET, MINEOLA, NEW YORK
PIONEER 2-8901

NEW PRODUCTS

able for guided missile computers and controls, automatic pilots, and weapons controls, as well as for nuclear reactors, steel mills, and various servomechanisms. Alpha cutoff frequency is rated at 25 Mc., with useful gain up to about 50 Mc.—General Electric Co., Syracuse, N. Y.

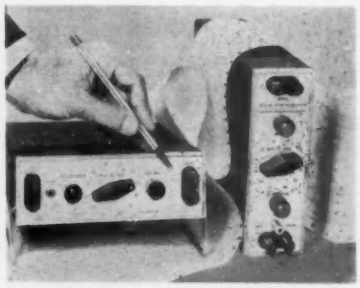
Circle No. 80 on reply card



RANGE EXTENDED

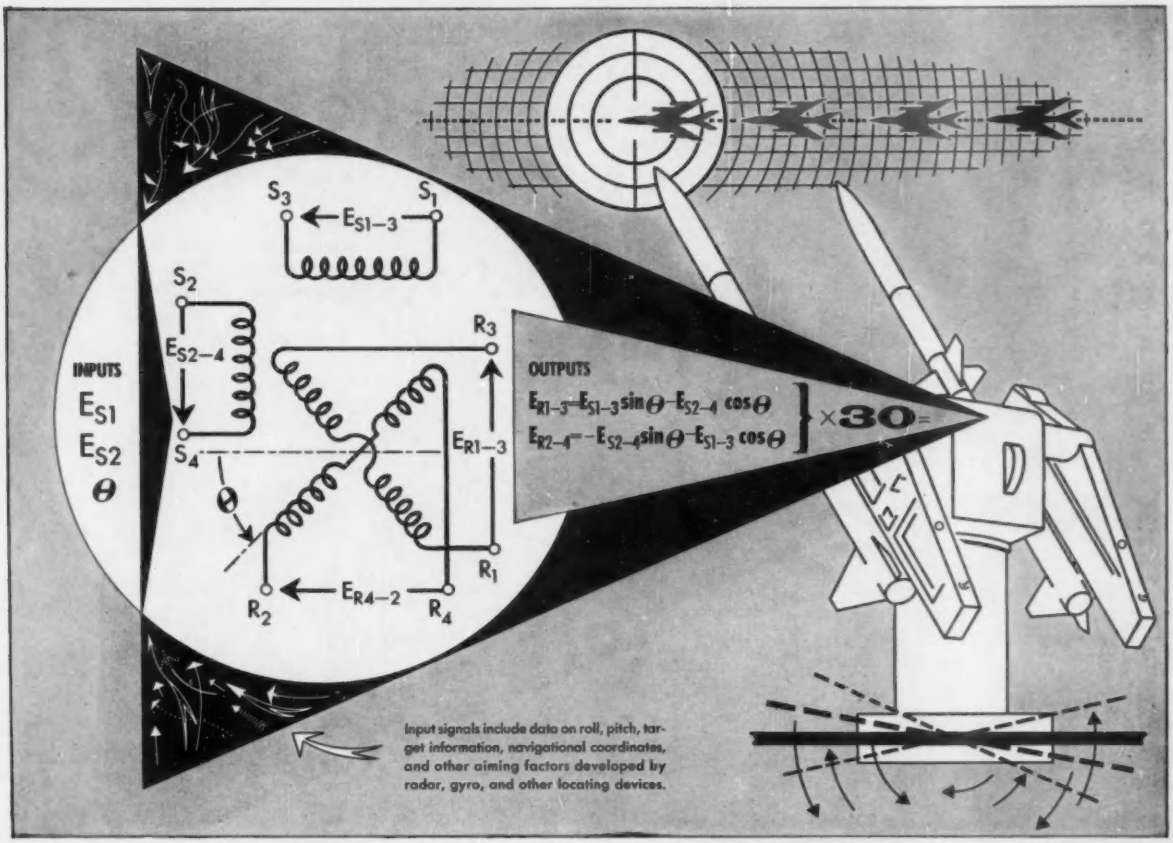
Frequency range of these new Magmeter detectors has been extended to 10 kc, twice the range previously available. Type F-5116, which produces 1 ma full-scale output from 0 to 10 kc, is particularly suitable for feeding recorders to provide a permanent record of frequency changes. Input voltage changes from 105 to 135 volts produce only about 1 percent change in indicated frequency. Output current is linear within 1 percent of full scale.—Airpax Products Co., Fort Lauderdale, Fla.

Circle No. 81 on reply card



USES NO CHOPPER

This completely transistorized, electronically modulated dc amplifier for milliameter recorders has 12 ranges of sensitivity, from 10 mv dc to 100 volts dc full-scale. It has a frequency re-



This **New** High Impedance Resolver by Norden-Ketay controls the Terrier missile from a rolling deck

Developed by Norden-Ketay for Navy Bureau of Ordnance

Take the computer problem in aiming a supersonic missile from solid ground — add the variable factors of a rolling ship and a jet-propelled, airborne target. The answer to that problem combines **30** Norden-Ketay precision resolvers in a phenomenal computer capable of launching the Navy's 'Terrier' with incredible accuracy.

Norden-Ketay standard 105D2V Resolver met these difficult requirements perfectly for the Navy's 'Terrier' project — again demonstrating the value of the special characteristics designed into all Norden-Ketay components.

If your problem concerns computer accuracy or power, consider Norden-Ketay Resolver advantages. The high impedance circuitry requires smaller volume and reduces the size of power supply equipment.

The high degree of accuracy and reliability of this new resolver helps the designer achieve new levels of performance in computer systems. Here is an outstanding example of the way Norden-Ketay developments simplify the solution of complex problems.

General Specifications

Norden-Ketay Type: 105D2V • Designated by BuOrd as Mark 4 Mod 1 Tuned Input: 12,000 ohms • Accuracy: ±0.1% • Frequency: 400 cps.

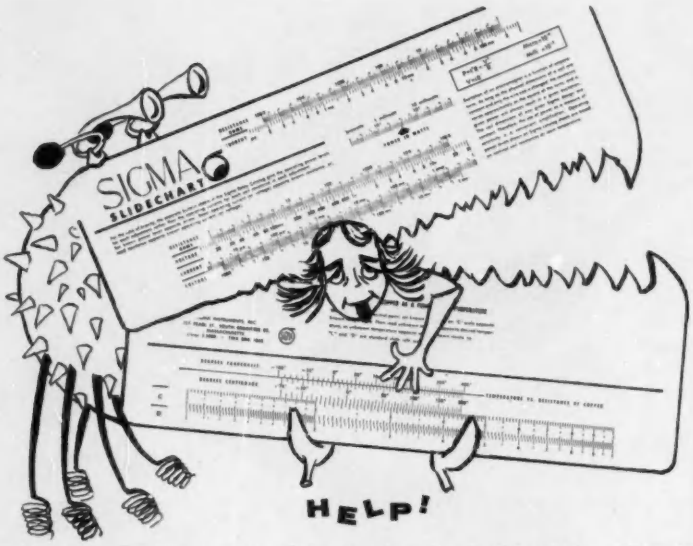
man's extending capabilities

N K

NORDEN KETAY

Write for additional data on high impedance and other resolvers to: Norden-Ketay Corporation, Precision Components Division, Commack, L.I., N.Y.

Sales Offices: Stamford, Conn. | Chicago Washington, D.C. | Dayton, Ohio | Los Angeles

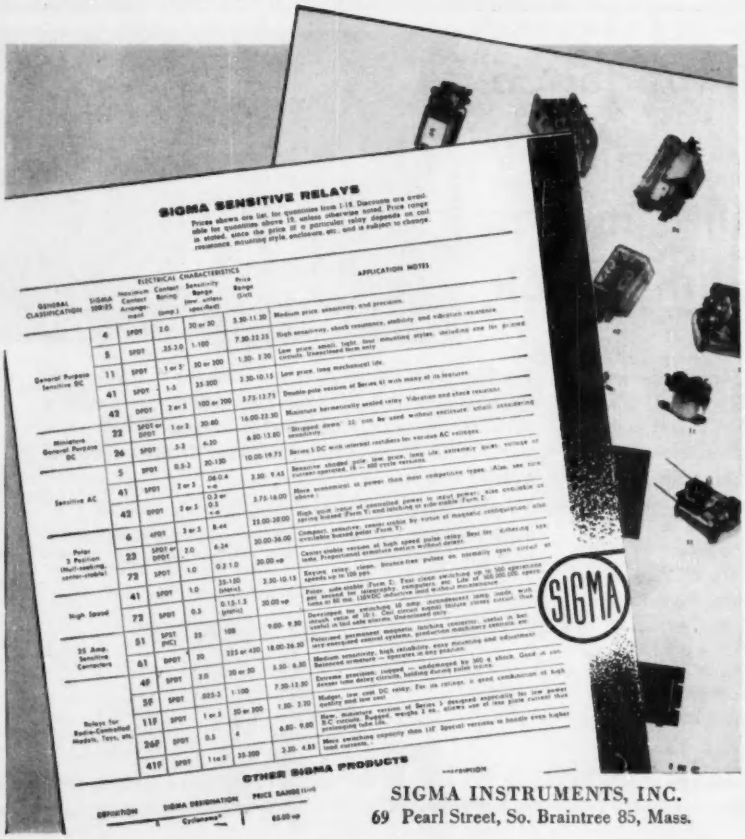


According to Mrs. L. B. Q. (who is pictured in the above candid photograph of the advertising department's mail department and is in charge of Sigma premiums, box tops, blown tops and the like) Sigma's July offer of free Slidecharts has turned into a polymorphous hydra.

Now it becomes necessary, due to the laws of Kirchoff and diminishing returns, to terminate the *free* offer. Hereafter we'll be glad to oblige, but at 25¢* (C. I. A.) per. (It's either this, fellows, or raising the price of Sigma relays.)

Don't think we do not appreciate the interest displayed — it's just . . . . Still free is the EBG reprint which resumés SIGMA products and is big enough so you can read it.

*Cash, stamps or rare fiduciary objects.



SIGMA INSTRUMENTS, INC.
69 Pearl Street, So. Braintree 85, Mass.

NEW PRODUCTS

sponse up to 50 cps, and since no vacuum tubes are used, it is extremely reliable, rugged, and quickly self-stabilized. It operates from either line voltage or a self-contained battery (a battery life of about 300 hours may be expected). Since modulation is accomplished entirely by electronic means, there is no mechanical chopper to introduce problems of noise, maintenance, and wear. Absolute accuracy is within 2 percent of full-scale.—Texas Instruments, Inc., Houston, Tex.

Circle No. 82 on reply card

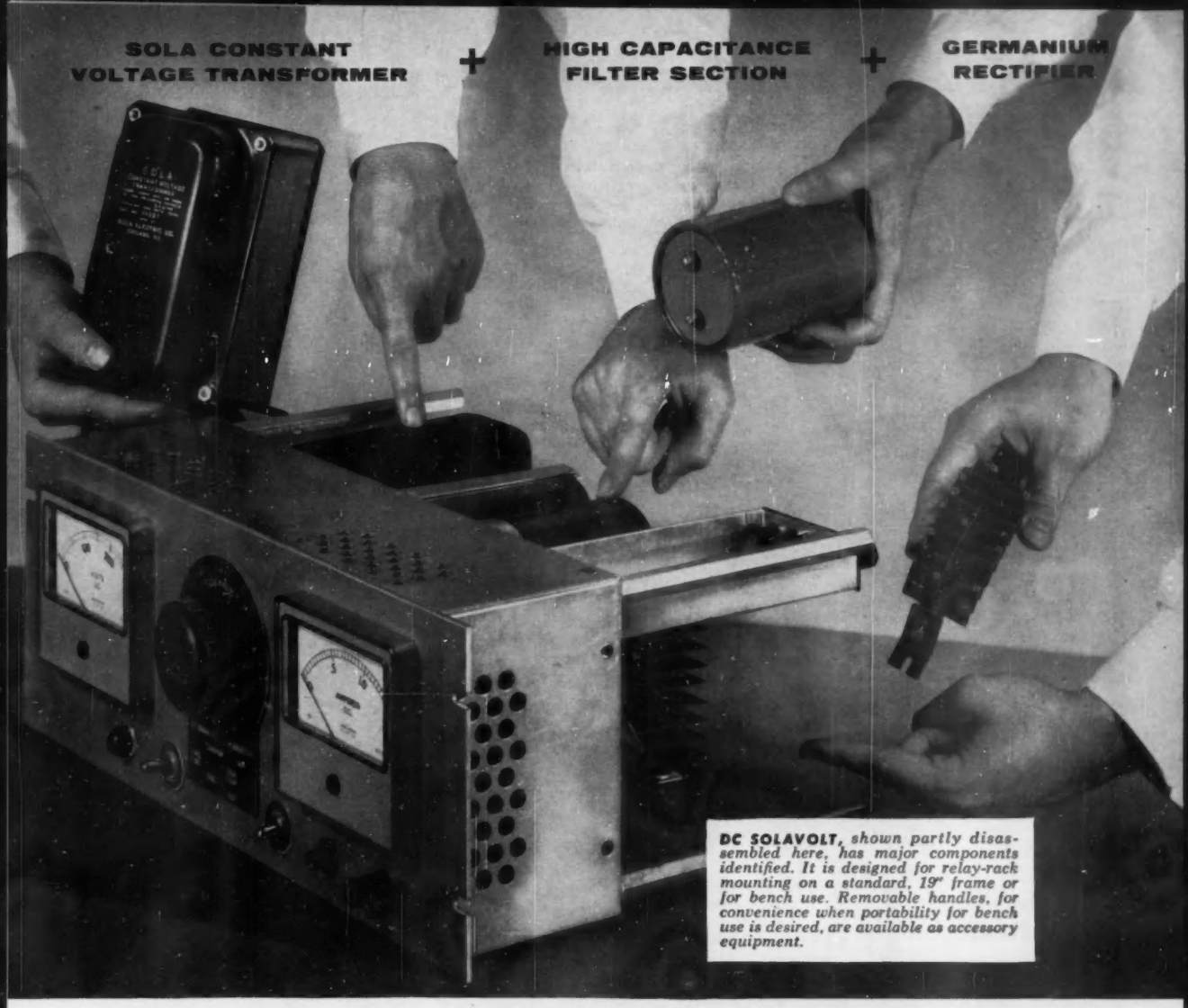
TORQUE BOOSTER

Type 141F12 Rotary Torque Booster offers reliable hydraulic amplification to reduce pilot effort in turbo-jet engine control. The unit amplifies torque input at an 8 to 1 ratio. Extreme reliability results from a unique dirt-insensitive servo valve construction coupled with complete protection against torque feedback to throttle input. Overloads up to 600 lb-in. will be sustained without damage.—Manning, Maxwell & Moore, Inc., Stratford, Conn.

Circle No. 83 on reply card

FLOATING INPUT

Type 1-100C dc amplifier, now available for thermocouples, strain gage bridges, and resistance-bridge transducers, features a true floating input and isolation of input and output from each other and from ground. Basically a carrier type, it uses a 400-cycle chopper modulator. Gain is continuously variable from 5 to 100 by means of a seven-positioner attenuator and



DC SOLAVOLT, *shown partly disassembled here, has major components identified. It is designed for relay-rack mounting on a standard, 19" frame or for bench use. Removable handles, for convenience when portability for bench use is desired, are available as accessory equipment.*

Unique combination of components in adjustable "DC Solavolt" regulated power supply reduces conventional size, weight, and cost

Compact size, low weight, high efficiency, and moderate price distinguish the new "DC Solavolt" from conventionally-designed, regulated, adjustable dc power supplies. These outstanding advantages have been secured by using a unique assembly of components (shown above) that occupy only 7" of height and 12¼" of depth on a standard, 19" relay rack frame.

Along with design simplicity, the "DC Solavolt" provides laboratory standards of performance:

OUTPUT VOLTAGE REGULATED WITHIN ±1% at full load with supply voltage variations up to ±15%. (Regulation within ±1.5% at 50% load and lowest voltage setting.)

RIPPLE VOLTAGE HELD WITHIN 0.10% (rms) at full load and nominal input voltage.

An important feature of this adjustable dc power supply is its ability to handle transient or "pulse" loads of up to twice the full load rating of the supply. The "DC Solavolt" has no tubes to replace, requires no "compensating" or "zero" adjustments, and needs no maintenance.

Six stock models provide outputs *adjustable in voltage ranges between 5 and 400 volts and load currents up to 7 amperes.* Your local electronic distributor now has the "DC Solavolt" in stock. He will be happy to give you further, technical information.

SOLA *Constant Voltage* **DC POWER SUPPLIES**

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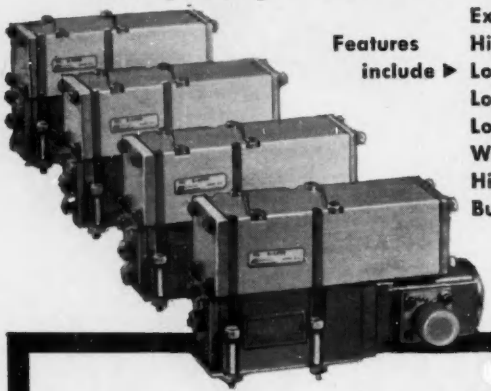
Now in mass production . . .
SANDERS SA-19 SERVO VALVE

The Sanders SA-19 Servo Valve provides unparalleled efficiency and reliability for a wide variety of electro-hydraulic components and systems. Utilizing the Sanders internal force feedback principle, this two-stage electro-hydraulic amplifier develops large hydraulic output flows with relatively low input electrical power requirements.



Features include ▶

- **Excellent Resolution**
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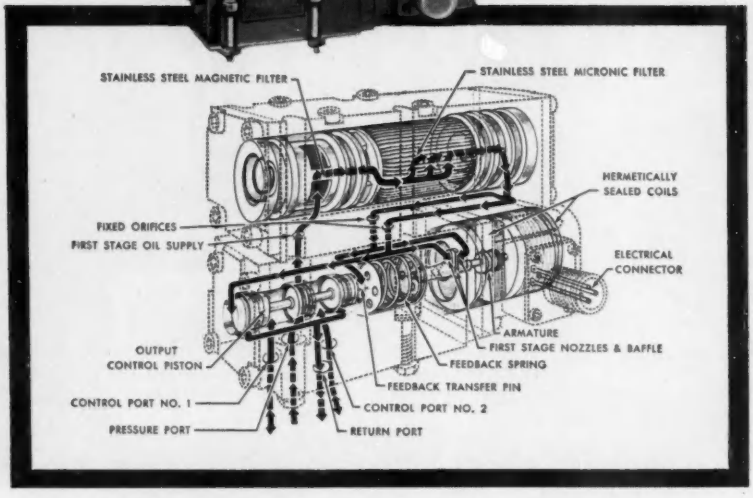
- **Built-in Filtration**



Operation: An input current, converted to a magnetic force in the First Stage Armature, moves the First Stage Baffle between two nozzles causing a pressure differential across the ends of the Output Control Piston. The resulting motion of the Output Control Piston is fed back through the Transfer Pin and Feedback Spring as a restoring force on the First Stage Armature, thus nulling the valve and porting oil to the load. The First Stage Oil Supply is thoroughly filtered as shown.

Typical Specifications The following are typical specifications for this valve. Higher pressure and higher frequency versions are also available.

Force Motor • Coil Resistance (ohms/coil) 400 • Differential Current ± 20 ma • Input Power 0.16 watts

Hydraulic Valve • Flow (GPM @ 1000 psi across valve) 10 • System Pressure (psi) 400 • Resolution (% of Full Signal) ± 0.125 • Hysteresis (% of Full Signal) ± 2.5

Write today for complete information.

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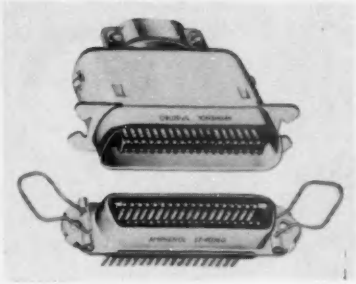
West Coast Field Office: 7335 VAN NUYS BLVD., VAN NUYS, CALIFORNIA, Tel. STATE 0-2720

a gain potentiometer. Specs include: linearity within 0.05 percent full-scale; long-term stability within plus or minus 0.2 percent full-scale; and long-term drift less than plus or minus 5 microvolts referred to the input. Input impedance is greater than 1.5 megohms; output impedance, 60 ohms.—Neff Instrument Corp., Pasadena, Calif.

Circle No. 84 on reply card

ACCESSORIES & MATERIALS



NEW CONNECTORS

Cable-to-chassis types have recently been added to this company's Micro-Ribbon series of connectors. Available in 14, 24, 36, and 50 contacts, the new models feature cadmium-plated brass shells with clear chromate treatment, gold-over-silver plated contacts, diallyl phthalate dielectrics. Truly miniature in size, a mated pair of the 50-contact size occupies only 3.7 cu in.—Amphenol Electronics Corp., Chicago, Ill.

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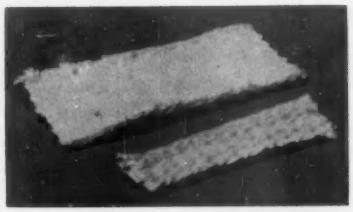

FOR SERVICE TO 1,500 DEG F

Two new insulating fabrics available for service up to 1,500 deg F, come in various widths and thicknesses, includ-

ing instrumentation tapes for insulation and leak detection. The tapes are made of Fiberfrax, a patented ceramic fiber. For instrumentation use, the tapes have two chromel wires embedded in them. A leaky metallic or radioactive fluid will quickly cause an alarm-sounding short-circuit.—The Russell Mfg. Co., Middletown, Conn.

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WELL-BALANCED

This miniature reducer, designed to specification MIL-R-8572 A, weighs from 0.17 lb to 0.25 lb, depending on the spring required, can be supplied with or without built-in relief valves, and adapts hydraulic applications. Completely balanced, it produces straight-line regulation with leak-tight shut-off, high rated capacity, and small initial pressure drop under flow conditions. Normal temperature range is minus 65 to plus 225 deg F for pneumatics; it is higher with modification of the internal design.—PneuHydro Valve Corp., East Orange, N. J.

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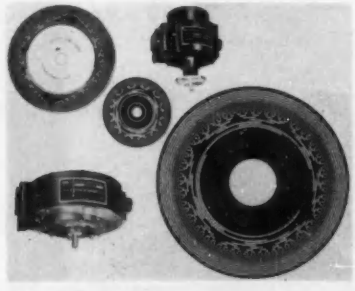
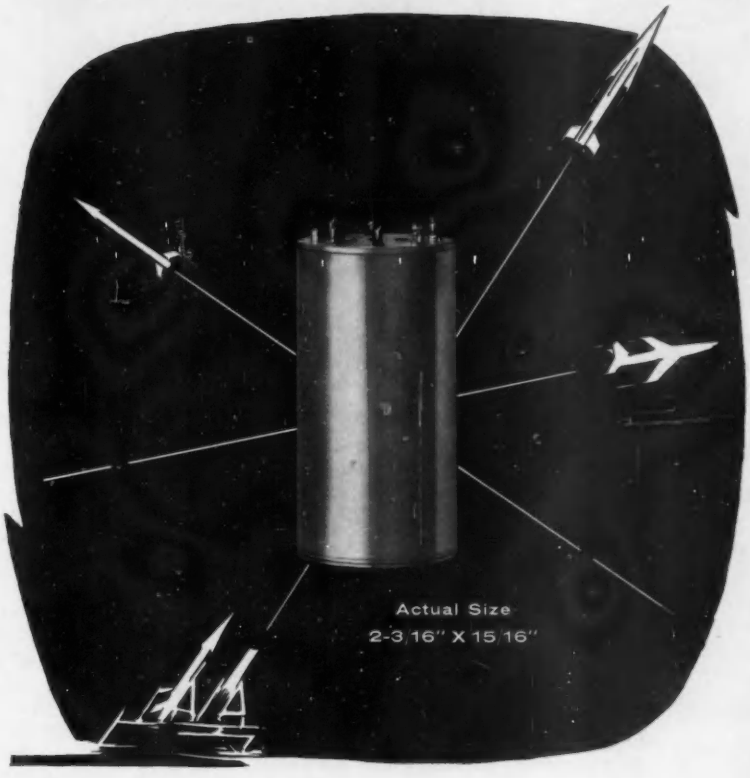


NEW CODE DISKS

High-accuracy discs for nonlinear and decimal codes are now available for this company's analog-to-digital shaft-position encoders. Patterns for trigonometric functions, logarithmic functions, and other nonlinear codes can be produced, providing the original data can be placed on IBM punched cards. Decimal-code discs, with divisions up to and including 100,000, are now being manufactured. A new 17-digit cyclic-binary-code disc, 15-in. in diam, has also been perfected and

Now in mass production . . .

SANDERS Subminiature RATE GYRO



To meet the growing demand for reliable control and stabilization elements, Sanders Associates is now mass-producing the Sanders sub-miniature rate gyroscope.

Exacting applications in aircraft, missile and fire control have proved conclusively the complete reliability of this rate gyro in a wide range of conditions and environments. Its features include:

- **Torsion bar suspension for fast response to minute signals**
- **Resolution of 0.001% full scale**
- **Compensated for environmental conditions**
- **Fluid cushioning to minimize vibrational shock**
- **Rotary multi-pole differential pickoff for higher sensitivity and excellent resolution**
- **Full scale ranges available up to 400° per second**

Sanders' direct distribution offers the long experience of Sanders engineers. Their assistance can be invaluable in reviewing your gyro design and application problems. Whether your problem is on selection of a gyro or a complete gyro control package, our Application Engineers are available to serve you.

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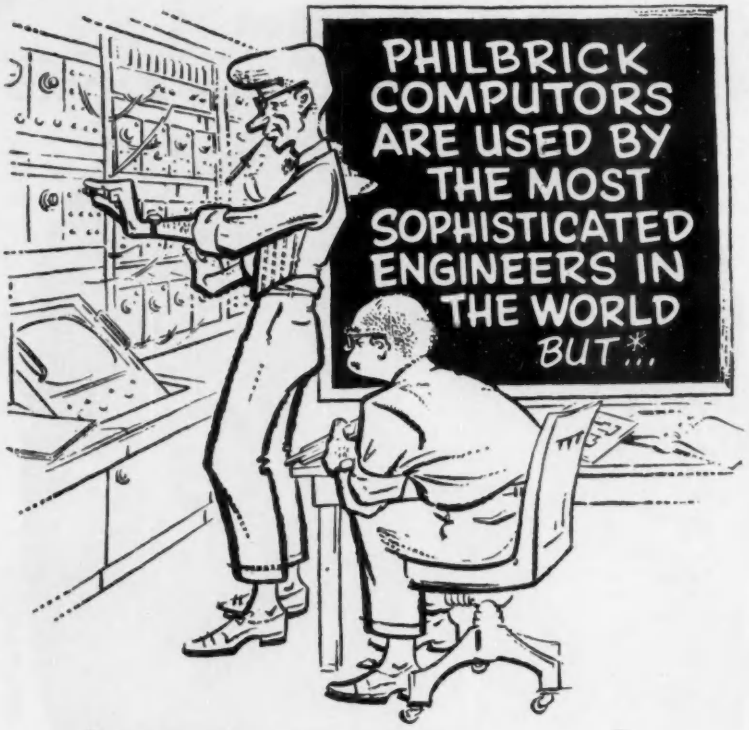

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Engineers, mathematicians and scientists can investigate their problems intimately and find solutions rapidly . . . typical computing times range from 50 milliseconds to 50 seconds.

* **YOU DON'T REQUIRE A MILLION DOLLAR BUDGET**

Prices for individual operational amplifiers start at $24, complete systems at under $1000. You buy only what you need for today's problems and expand as necessary.

* **YOU DON'T NEED AN ELECTRONICS EDUCATION**

The block diagram approach simplifies the set-up. You have only to interconnect functional building-blocks to simulate any system, from *aeronautics* to *zymurgy*.

Write to George A. Philbrick Researches, Inc., for Catalogue 103.

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NEW PRODUCTS

a new encoder is being manufactured to house it.–Baldwin Piano Co., Industrial Sales Div., Cincinnati, O.

Circle No. 88 on reply card

LIGHTWEIGHT CABLE

The introduction of the new multiconductor, ribbon-like electric Tape Cable should give rise to some new concepts in the field of electrical design. The cable consists of a flexible film of polyester insulation in which are imbedded flat copper conductors only 0.0015 in. thick with 0.1-in. center-to-center spacing in conformity with RETMA recommended grid pattern for printed wiring. Nine Standard cable sizes have been established, with 9, 14, 17, 21, 27, 30, 36, 40, or 50 conductors. Its very low interconductor capacitance suits the cable for high-frequency applications.–Tape Cable Corp., Rochester, N. Y.

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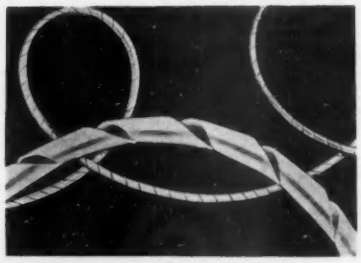

SPIRAL-CUT NYLON

Spiral-cut nylon tubing, now available in OD's of $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$ in., can be used to bundle diameters up to 1 full inch and is easily cut to any desired length. Nylon's toughness, resistance to abrasion, low surface friction, and other distinctive features can be used to advantage.–The Polymer Corp. of Pennsylvania, Reading, Pa.

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(100) PHOTOCONDUCTORS. Electronics Corp. of America. Bulletin TR-101, 8 pp. Takes a detailed look at the semiconductor-photoconductor material known as lead sulfide, giving its general characteristics and cell types. Response charts and actual-size photos enhance the text.

(101) ANALYSIS OF SOLIDS. Scientific Instruments Div. of Beckman Instruments, Inc. Technical data sheet IR-74-MI(T), 4 pp. Deals with the preparation and handling of potassium bromide as a matrix material in infrared studies of solids. The unique sampling technique concerned also gets good treatment, and the references to the literature are generous.

(102) FLUOROSCOPY FOR METALS. Instruments Div. of Phillips Electronics, Inc. Folder, 6 pp. This "Nondestructive Testing" reprint covers the application of electronic fluoroscopy to the examination of metals, particularly to thick steel and aluminum sections. Special instruments are also described.

(103) ELECTRONIC GALVANOMETER. Kin Tel. Bulletin 14-3, 2 pp. One way to use the new Model 204A is as a stable dc amplifier, says the bulletin. It lists these characteristics, among others: plus or minus 10 microvolts or 0.001 micro-amp full-scale sensitivity, 10,000-ohm input resistance, and seven ranges.

(104) DATATRON APPLICATIONS. ElectroData Div. of Burroughs Corp. Six brochures. Their subjects and numbers are as follows: payroll processing, 4-05-020; invoice billing, 4-05-010; parts inventory controlling, 5-01-110; accounts payable processing, 4-05-030; utility billing, 4-04-020; and insurance recording, 4-02-120.

(105) INTERVAL TIMER. Cramer Controls Corp. Bulletin PB-271. Gives details on construction, operation, and applications of Type 271, a new, manually set, motor-driven unit. Range selections, ratings, switch capacity, and information on accessories included.

(106) CYCLING TIMER. Cramer Controls Corp. Bulletin PB-571. Similar information for this unit is given as for the one in 105. Several nonstandard arrangements for special applications, as well as instructions on specifying program schedules are included.

(107) HEAVY-DUTY RELAYS. The Arrow-Hart & Hegeman Electric Co. Booklet, 8 pp. Describes interchangeable multiple pole and fixed multiple pole versions of these versatile machine-tool devices, which can be adapted to a plug-in receptacle or to a latching attachment. Among the specs: 10 and 15 amp, 600-volt maximum, 2, 3, 4, 6, and 8 poles.

(108) TRANSISTOR CHART. General Transistor Corp. Wall chart. A turn of your head is all that's needed to get a good idea of the applications, maximum ratings, and typical characteristics at 25 deg C of 56 kinds of germanium-junction alloyed transistors. Also in view: an interchangeability table, transistor-case outlines, circuit diagrams, and standard IRE symbols.

(109) MOTORS. Marathon Electric Mfg. Corp. 1957 condensed catalog, 4 pp. Gives prices, slide-base dimensions, adapter information, etc., for general-purpose fractional and integral horsepower motors ranging from 1/20 to 200 hp. Also carries standard modifications and dimensional drawings. Based on 300 pages of data.

(110) STRIP CHARTS. Leeds & Northrup Co. Product data sheet 463, 8 pp. Presents full-size reproductions of plant operating chart records obtained with L&N Speedomax recorders to illustrate their readability, versatility, and speed. Single- and multipoint machines described.

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(111) VISCOSE ANALYZER. Dynamics Research Associates. Report 66-R8. Covers the "dynateq" R-8 filtration process analyzer, which automatically measures and records weight and weight-rate, the two main variables in determining the plugging value of viscose.

(112) SERVOBOARD INSTRUCTIONS. Servo Corp. of America. Bulletin SBI-Rev. 1, 8 pp. This is more than an instruction booklet for Servoboard assembly kits. Most of it, in fact, is devoted to tables of common gear ratios and moments of inertia, in which Servo Corp. does no horn-tooting at all.

(113) FLOWMETER SELECTOR. Brooks Rotameter Co. Bulletin 110, 4 pp. Point the arrow on the die-cut to the flow range in your application, and this guide will suggest a proper flowmeter and give its maximum operating pressure (in psig) and maximum operating temperature (in deg F).

(114) WORK-PLANNING. Wallace Clark & Co., Inc., management consultants. Report, 12 pp. About a specialized service that "embraces thinking through the detailed steps which must be taken to carry out a given project, making appropriate arrangements to accomplish each step in proper sequence, and comparing, reconciling, and coordinating the cost and timing of each of these steps with overall Company, calendar, financial, and manpower objectives." Engineering and R&D jobs are the target.

(115) TIMING. The Haydon Mfg. Co., Inc. Catalog 571, 30 pp. Dimensional drawings, circuit diagrams, and standard specs cover timing motors (hysteresis, inductor, clutch, reversible, dc, miniature, heavy duty), timers (time delay, interval, cycle), elapsed-time indicators, and rectangular and round clock movements.

(116) SEISMIC DATA PROCESSING. Texas Instruments, Inc. Bulletin S-318, 6 pp. Describes "the only all-electronic seismic data processing computer on the market", showing how its constant-correction unit corrects a seismogram for weathering and elevation variations and pointing out other features, too.

(117) PROVING RINGS. Morehouse Machine Co. Brochure, 12 pp. A handsome, black and white illustrated treatise on the Morehouse proving ring, a device for testing the accuracy of weighing and measuring systems by translating and comparing a change in the ring's diameter.

(118) PULSE CALIBRATOR. Electronic Instruments Div. of Burroughs Corp. Brochure, 4 pp. All about a signal-measuring device (signal can be ac, dc, or pulse) that works on the reference-voltage principle. Calibrated dial used to vary the reference has 1,000 divisions. It was specifically designed for the evaluation of magnetic cores.

(119) MICROWAVE TUBES. Tube Div. of Varian Associates. Catalog, 32 pp. Microwave tubes arranged by power and frequency for these applications: communications, radar and navigation, severe environmental service, and test and instrumentation. Includes 14 pages of data on individual tubes.

(120) DC AMPLIFIER. Kin Tel. Data sheets (separate), 8 pp. Describes the Model 111A, a broadband integral-power supply unit with low drift and low output impedance, and high output level and high input impedance. Meets requirements for an operational amplifier for computers, simulators, industrial controllers, etc.

(121) VIBRATION METER. Consolidated Electrodynamics Corp. Bulletin 1538C, 4 pp. Tells about Type 1-117, which indicates directly, on a large meter, average vibration velocity and peak-to-peak displacement. Three high-pass filters can be used at one time. Five of them are available.

(122) RECORDING OSCILLOGRAPH. Consolidated Electrodynamics Corp. Bulletin 5-122, 6 pp. Says this true environmental unit can operate in a range of from minus 65 to plus 250 deg F, at altitudes up to 120,000 ft, and on the other side of what has been known as the "thermal barrier" for oscillographs. Some other specs: 26 recording traces, two reference traces, 12,000 in./sec or faster writing speeds, 12 recording speeds.

(123) SPECIALIZED CONTROLS. Isotope Products. Bulletin 19, 8 pp. Describes two instruments designed specifically for paper-machine measurement and control: the Betameter, for measuring basic weight, and the Aquatel, for measuring sheet-moisture content. They traverse the sheet simultaneously.

(124) COUNTING THE MOLECULES. Brookfield Engineering Laboratories, Inc. Data sheet 020, 4 pp. An illustrated discussion of the viscosity-measuring "Viscometran" and its application to end-product determination of polymerization reactions, or the molecular construction of manufactured material.

(125) ELECTRIC MOTORS. The B. A. Wesche Electric Co. Bulletin BAW-56, 8 pp. Contains photos, drawings, specifications, applications, ideas, and functions of a variety of Wesche torque and special-design motors, and collector rings.

(126) VHS METER-RELAYS. Assembly Products, Inc. Bulletin 104-A, 12 pp. Explains various features of this meter (locking-coil, signal-input coil, overload protection, thermistor control), illustrates the basic meter-relay circuit, and goes into detail on circuitry. Model 266, the star attraction here, is shock- and vibration-resistant, withstanding 10 g's or better.

(127) AVOIDING MAGNETIC HUM. Magnetic Shield Div. of Perfection Mica

Co. Data sheet 129, 4 pp. Series of photos shows how this company's Co-Netic foil goes around audio transformers, chokes, and other square or rectangular components to shield them against hum.

(128) MAGNETIC TAPE. Instrumentation Div. of Ampex Corp. Catalog 10M-4-57, 16 pp. Spells out major areas of magnetic tape instrumentation, gives specific examples of how the tape can be supplied in these areas, and offers some general data on performance. Also touches on techniques, tape systems, and one or two other things.

(129) AUTOMATIC VALVES. A. W. Cash Valve Mfg. Corp. Condensed catalog P&H 57, 12 pp. Covers main uses, installation tips, and construction features of the complete line of Cash automatic valves. Each principal series is presented with its own specification table, and there are 30 of these tables.

(130) SMALL-CASE INSTRUMENTS. Fischer & Porter Co. Catalog 51-1450, 16 pp. Small process instruments for measuring, indicating, indicating and transmitting, and indicating and controlling laid out in handsome, two-color format. All are in F&P's new 1450 series, which features fiber-glass reinforced housings.

(131) REFRACTOMETER. Consolidated Electrodynamics Corp. Bulletin 1833, 8 pp. Describes a process instrument that measures the difference in refractive index between a liquid standard and a flowing liquid sample by means of a beam of light. Among its uses: blending control, fractionating control.

(132) MASS SPECTROMETER. Consolidated Electrodynamics Corp. New product announcement, 6 pp. Deals with a rugged, portable instrument for plant or field batch or process analysis. It features high sensitivity, good reproductibility and an overall mass range of 2 to 80. Construction is modular.

(133) TRANSFORMERS. Laboratory For Electronics, Inc. Bulletin TR500, 4 pp. Describes a line of military and commercial transformers manufactured to customers' spec. Some of the types discussed: high power pulse, subminiature binary, hermetically sealed military, and open-type military. Company facilities are also mentioned.

(134) PRESSURE REGULATORS. Spence Engineering Co., Inc. Brochure No. 1011, 4 pp. First presents a general outline of the advantages of the company's pressure regulators, and then proceeds to selection data on three different pilots and three different main valves. Several typical applications shown on the cover.

(135) WELDED BELLOWS. The Belfab Corp. Catalog No. 2, 8 pp. Discusses the design and general characteristics of welded bellows of stainless steel and other alloys. Spring rate, life expectancy, pressure, and hysteresis are some of the characteristics covered.

(136) DRIVE COMPONENTS. Cycledynamics Inc. Bulletin CD-557, 12 pp. Describes the Cycledyne electro-magnetic cycling drive unit, gives seven reasons why the unit should improve plant operation. Typical mounting options and assemblies are tabulated. A chart shows how to interpret model numbers.

BIDDLE Instruments

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...the new Frahm® Resonant Reed Relays and Oscillators together with packaged tone generator and tone detector circuits...the wide line of Frahm Frequency Meters including the improved precision sealed types...the Biddle Corona Testing Equipment and hear all that's new in this field for non-destructive evaluation of electrical insulation in transformers, cables, capacitors, and other electrical components for ionization starting voltage at 60 cycles...the improved Meg type of Megger® Insulation Tester with multiple switch and dual voltage facilities including double range megohm scale, ohm scale, and capacitance discharge ...the new Biddle Low Resistance Ohmmeters.

IT PAYS TO VISIT TRADE SHOWS

Most men in management encourage trade show and conference attendance by their operating staffs and many attend themselves. It is perhaps the only way they can hear so much, and see so much that is new, in a short space of time. There is real economy in being able to examine hundreds of manufacturers' products and sit in on shirt-sleeve sessions on everyday problems with practical men—specialists in their fields.

Write for Complete Check list of Literature 19-57-CE.

B-711

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Laboratory & Scientific Equipment

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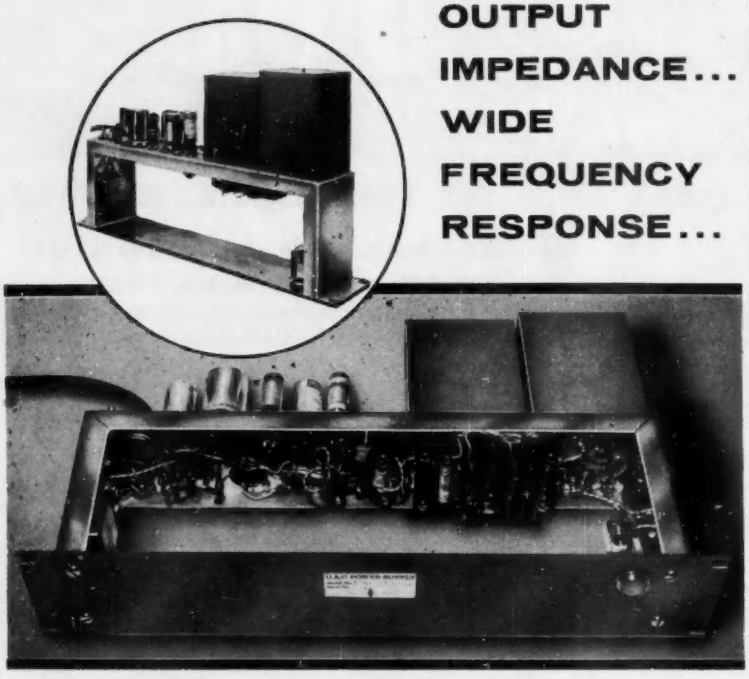

LOW OUTPUT IMPEDANCE... WIDE FREQUENCY RESPONSE...

UAC Transistorized Computer Power Supplies

- for Airborne Applications
- for Portable Instruments
- for Line Operation

UAC Multiple Computer power supplies are reliable, compact, versatile units with 115v 400cps input for airborne applications, 24 VDC for portable instruments, and 115v 60cps for line operation.

These units provide exceptional performance under intermittent variable and pulse loads. They have low output impedance (DC to 100Kc) and regulation is available to 0.1%.

They operate efficiently over the temperature range −55° to ±55°C. Operation to 85°C is available.

Typical output voltages and currents follow. Units with all 7 outputs are available from any of the inputs listed above.

Line operated unit fits a standard 19" x 8¾" relay rack and weighs approximately 22 lbs.

+30 volts DC @ 2 Amps—Regulation 1%
+10 volts DC @ 6 Amps—Regulation 1%
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−10 volts DC @ 5 Amps—Regulation 1%
−11 volts DC @ 3 Amps—Regulation 1%
−30 volts DC @ 5 Amps—Regulation 1%

Tell us your specific requirements.

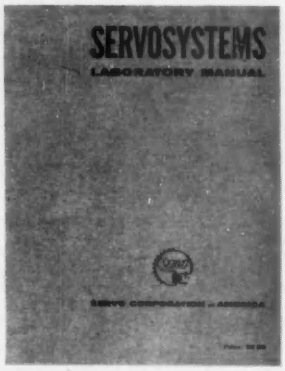
UAC® Electronics
A DIVISION OF
Universal Transistor Products Corp.

Dept. C 97 • 36 Sylvester St. Westbury, L. I., N. Y. • Edgewood 3-3304 • Cable Address: UNIVATOMS

APPLICATION LITERATURE

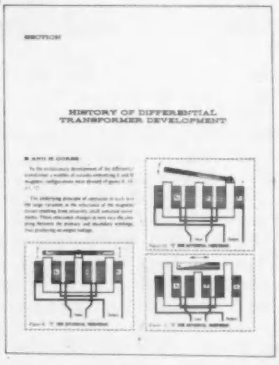
NOTE: Because some of the items below are "priced", we have omitted card numbers and suggest that interested readers write directly to the companies involved.

LAB MANUAL. Educational Services Dept., Servo Corp. of America, 2020 Jericho Turnpike, New Hyde Park, N. Y. Entitled "Servosystems Laboratory Manual", this 32-page booklet is designed to furnish the framework for an introductory lab course in servomechanisms, feedback control systems, etc. It includes seven in-

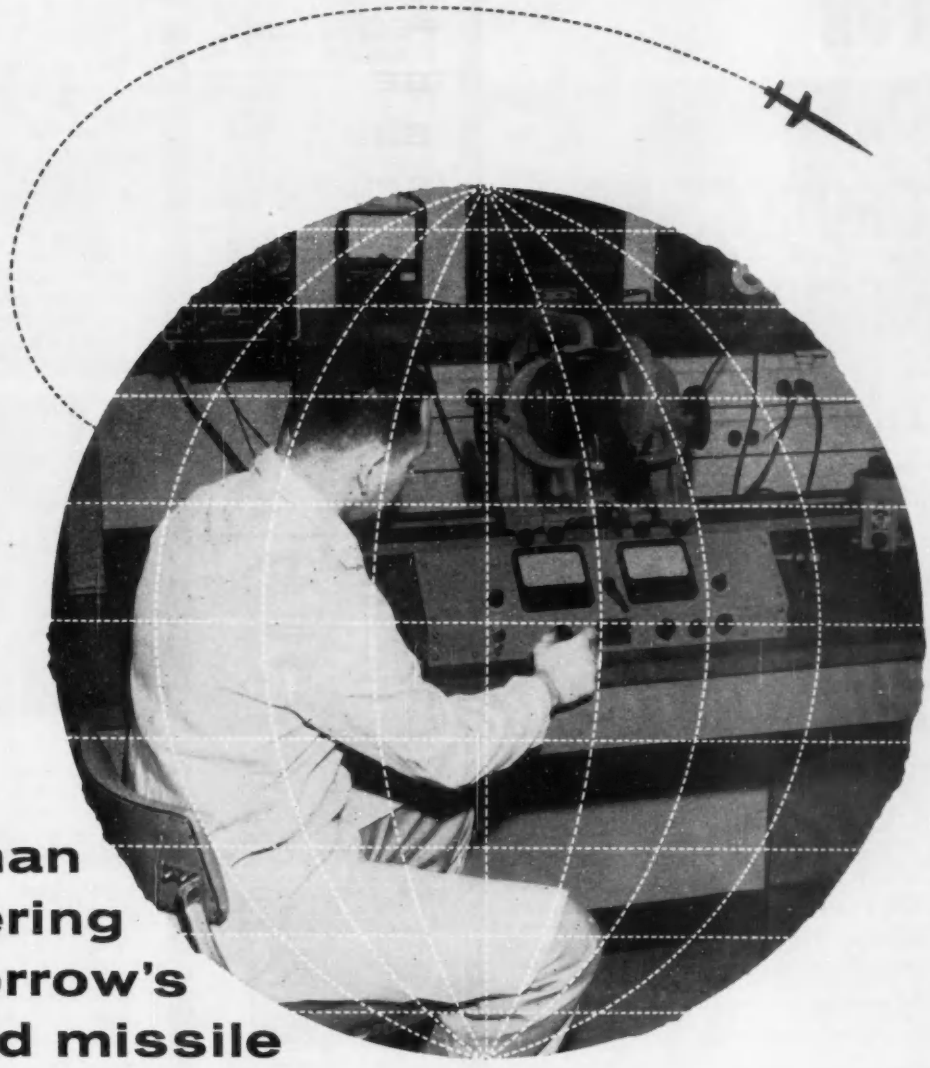


tegrated, class-tested experiments, each of which builds on what the student has learned in the ones before. Theoretical discussion is held to a minimum and confined to the introductory section. The experiments call for the breadboarding of a typical ac positional-feedback servomechanism, which is then used throughout the course. Price $2.

DIFFERENTIAL TRANSFORMERS. Automatic Timing & Controls, Inc., King of Prussia, Pa. Beginning with basic theory, this new handbook describes characteristics, applications, and limitations of differential transformers. Section II, starting



on page 6 (see cut), presents a well-illustrated discussion of the history of differential-transformer development. Some special design considerations are treated in Section V. A few of the typical applications illustrated in the final section include thickness and tension controls, a pressure-compensated gas flowmeter, and a differential



This man is steering tomorrow's guided missile

His uniform is a laboratory coat, his cockpit a dust-free room with carefully controlled temperature and humidity. He's a skilled General Mills gyro technician—as much a part of the defense of his country as the jet pilot. Results from his work, and from work in other R & D labs, assure us that tomorrow's guided missiles will be even more accurate than today's. ¶ At the Mechanical Division of General Mills, the gyro lab is part of a talented, well equipped guidance and navigation systems development group. The group also includes top men and facilities in infrared, microwaves, electronic and mechanical design, and overall systems engineering. We team these men and facilities with a complete precision production plant to handle systems, sub-systems and major assembly problems for the world's most exacting customers. Possibly you too can benefit from our capabilities.

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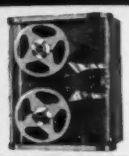
FOR DATA PROCESSING COMPONENTS AND SYSTEMS

SPECIFY POTTER

Potter instruments and systems are unexcelled in reliability, accuracy and flexibility. The equipment shown is typical of many more available as individual components or in integrated systems to meet specific requirements.

Write for brochure describing these and other Potter units, including special products. For detailed technical specifications on any of the Potter Products listed above, contact your Potter Representative or the factory.

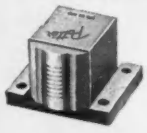
DATA-HANDLING EQUIPMENT



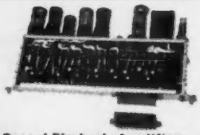
Digital Magnetic Tape Handlers

Perforated Tape Readers

"Quick Look" Recorders



Record-Playback Head Assemblies



Record-Playback Amplifiers

PRESET INTERVAL GENERATORS

Preset Interval and Delay Generators

HIGH SPEED ACCESS REGISTERS

Ten-Bit Parallel Output (Serial Input) Using Magnistors

Ten-Bit Serial Output (Parallel Input) Using Magnistors

Six-Bit Digital Comparator Using Magnistors

POTTER INSTRUMENT COMPANY, INC.
115 Cutter Mill Road Great Neck, L. I., N. Y.

WESCON Booth 1003; ISA Booth 1266

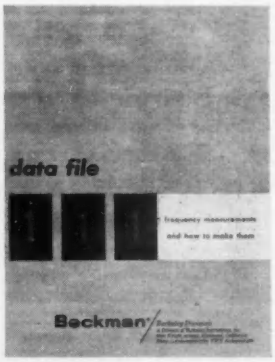
APPLICATION LITERATURE

diaphragm pressure transmitter. Request Handbook No. R-50. Price: $2.

INFRARED IN AVIATION. Barnes Engineering Co., Stamford, Conn. "INFRARED: An Appraisal of Its Role in Missile Guidance, Target Detection, Fire Control, and Mapping", is the title of this 20-page brochure. It objectively surveys infrared's potentialities and shortcomings for use in military systems, particularly as compared to equivalent radar systems. Primarily, it reviews the development of IR, its techniques and instrumentation, and its applications. Author is Philip J. Klass, Avionics Editor of Aviation Week, whose reprinted articles appear here with marginal comments pointing out Barnes' con-

tributions in the field. Some readers may have recognized the photo above as being an infrared picture of lower Manhattan Island. Interestingly enough, the picture was made six years ago, with equipment now considered obsolete. Free on request.

MEASURING FREQUENCIES. Dept. 7242, Beckman/Berkeley, 2200 Wright Ave., Richmond 3, Calif. Data File 111, 17 pages on "frequency measurements and how to make them", covers the equipment used in measuring and indicating, in digital form, frequencies from 0 cps to 1,005 mc. Low and medium frequencies



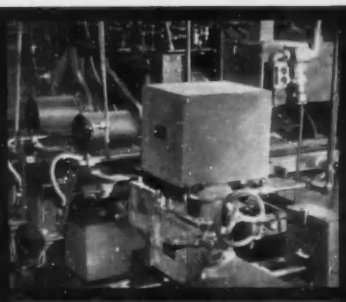
are discussed in one section; rf, vhf, and uhf in another. A separate section covers period meter and preset counter techniques as applied to rapid measurement of low frequencies. Free on request.

CREATED FOR THE JOB

by CONOCONTROLS Specialists

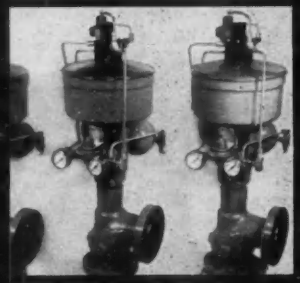
Conoflow LB Valve on a difficult liquid level control job in a Barrett Div. plant of Allied Chemical & Dye Corp. This valve is handling hot coal tar at temperatures to 750° F.

Conoflow Saunders Valves used in conjunction with Fuller Company's Airveyor System in a midwestern cement plant. These close-coupled "on-off" valves are equipped with solenoids and armored position indicators.

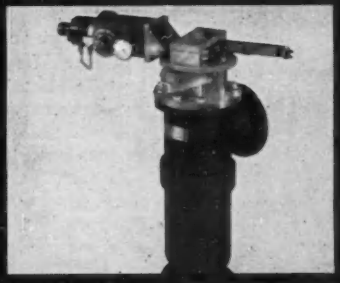


One of several Conoflow Rotomotors on a unique service in Owens-Corning's Newark, Ohio plant. This powerful pneumatic actuator positions a large circular saw which automatically trims and cuts a continuous sheet of Fiberglas into stock widths.

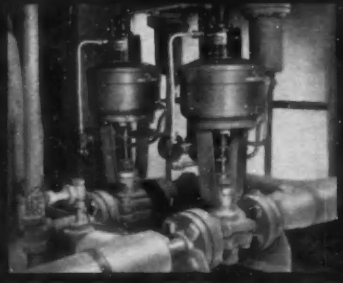
Conoflow Pressure Transmitters for the Kraft Foods Company. They will be used with miniature recorder-controllers to give visual indication and record of levels and pressures in vegetable oil vessels.



These 3" Conoflow "S" Valves are going to the Aluminum Co. of America in the new St. Louis pilot plant. They will be handling hot flashing caustic liquor containing 7% suspended solids with pressure drops up to 300 psi.



Cylinder Conomotor affords remote manual or automatic adjustment of flow rate for a Kates direct-acting flow regulator. This is one of many OEM applications for Conoflow's versatile pneumatic throttling actuator.



These Conoflow LB Valves have been on a tough temperature control service for over three years in the plant of this large manufacturer of floor covering and insulation. More than 600 Conoflow LB Valves are in use throughout this plant.

Conoflow Airpak filter-regulators being tested prior to shipment to duPont. Other large volume Airpak users are: Phillips Petroleum, Leeds & Northrup, Catalytic Construction, Minneapolis-Honeywell, and Fischer & Porter.

While most Conoflow products are shelf items—a good many are not. They are created for the job through our engineering and yours—combined and concentrated on your problem. Shown above are only a few examples of the variety and scope of Conoflow installations. If you are not already a Conoflow customer, phone or write us at 2100 Arch Street, Philadelphia 3, Pa. We'll put you in touch with a Conoflow representative qualified to help you.

See us at the I.S.A. SHOW—*Booth 1455*

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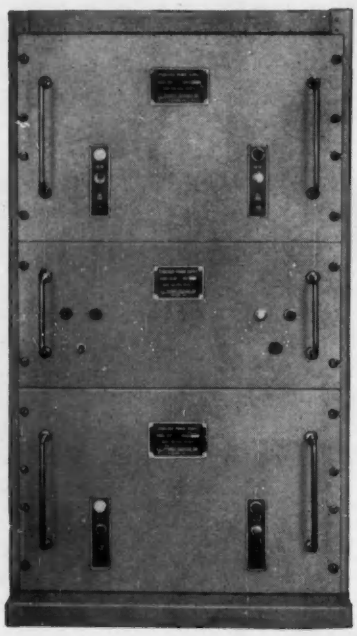
CONOFLOW CORPORATION

FOREMOST IN FINAL CONTROL ELEMENTS

SUBSIDIARY OF WALWORTH



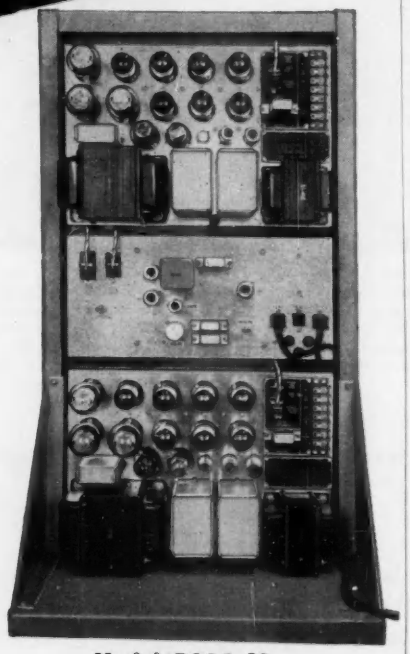
.01%
COMPUTER POWER SOURCE
and
VOLTAGE REFERENCE

RECOGNIZED RELIABILITY

Model D305-CS is a dual stabilized D-C source consisting of two voltage regulated power supplies symmetrical to .01% with respect to ground and referenced to a .005% zener junction diode network in a temperature stabilized oven. Ripple output is less than 500 microvolts. Response time for step changes in load from zero to maximum rated current is less than 50 micro-seconds. Internal impedance is less than 0.3 ohms to 20 kc, less than 1 ohm to 200 kc. Prototype models have maintained better than .01% stability for periods in excess of 10,000 hours.

Standard models are available in voltages ranging from 100 to 500 volts and currents from 100 to 500 milliamperes. Output voltages may be identical or supplied in fixed voltage ratios. Output voltmeters and milliammeters optional.

Write for Catalog 58C for complete details.



Model D305-CS (pictured)

Plus and minus 300 volts D-C, 0-500 MA Standard 19" rack mounting. Height 33¼"

Supplied less rack

Power Designs inc.

89-25 130th STREET
RICHMOND HILL 18, N. Y.

STABLE POWER SOURCES FOR ELECTRONIC INSTRUMENTATION

WHAT'S NEW

(Continued from page 62)

was a small company (under 500 people) only a few years ago. It devised a new method for making jet-engine blades, a method that sliced the time for such complex operations as measuring, casting, and grinding, and still resulted in a high-class product. Today Thompson is no longer listed as "small". Some other cases are detailed in a GE pamphlet titled "How General Electric is Helping Its Small Business Defence Subcontractors", January 1956 (16 pp.).

• **It's more than bidding**—Small control companies, says Metcalf, are well aware of the potential profit in subcontracting on production orders, but they sometimes overlook the benefits from subcontracting on R&D jobs. This is quite true, but here, too, there is no one-way street. Small businesses may be missing a lot of opportunities all over, but that doesn't mean that they just have to go after the additional business and it's theirs. GE, and other large companies like it, may have to abide to a certain extent by the outcome of bids, but they can still make a choice or at least express an opinion.

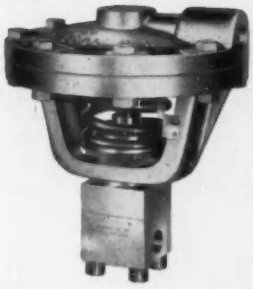
In fact, the more complex and vital the control part or system to be subcontracted, the louder the big-company voice in the selection of the vendor. This is only natural, and even the Federal government acknowledges it: the more important the job is, the less secure one can feel in simply relying on the lowest bidder to accomplish it. Fortunately, though, it usually turns out that a company is low bidder because it has the means, in terms of facilities and personnel, to do the job for the least money.

But because the prime contractor takes all responsibility in a contract, no matter how much subcontracting is done, a visit by a GE man to a possible subcontractor usually precedes an invitation to bid. This invitation, then, means the small company is qualified in many areas, only one of which is facilities and staff. Among the others listed by Schnell: ability to produce materials and clearance for reasons of national security.

Raytheon Sells Datamatic Stake; M-H Now Sole Owner

Raytheon Mfg. Co.'s 40-percent stock interest in Datamatic Corp., the firm that it formed with Minneapolis-Honeywell Regulator Co. in 1955, has

MINIATURIZATION From Pilot Plant to Process



"BANTAM" 500 SERIES VALVE

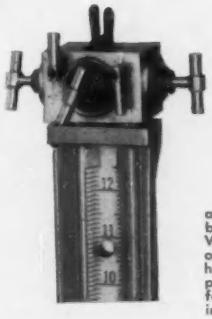
Throttling "Bantam" Diaphram Control Valves for all standard control valve uses, Cv of 0.6 and below, up to 1000 psi and 500°F, characterized, renewable trim, 316 stainless steel and *Teflon* only wetted surfaces, low in hysteresis size and weight, 2000 series "Bantam" Control Valves available for on-off service.

MINIATURE DIAPHRAGM OPERATED SHUT OFF VALVE

Body PVC, diaphragm neoprene, diaphragm head aluminum. Body and operator 2" dia. x 1¾" high. (⅛ or ¼ NPT).

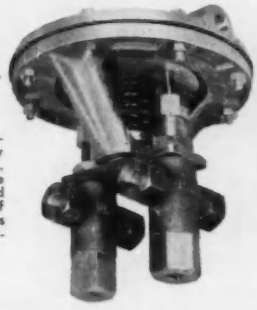
"DEMI" PACKLESS VALVE

For services when packing is a problem, manifolding of small valves in one unit at low cost. For services up to 750 psi and 500°F, screw, toggle, or diaphragm operated, the "DEMI" line is ideal for panel mounting up to five valves in one block.



"DEMI 54"

5 Valve Manifold for integral mounting on cleanout type Manometer. Packless design, 2 shut off valves, one bypass valve, 2 vent valves. Other 3 or 5 valve models available with or without special manometer mounting.

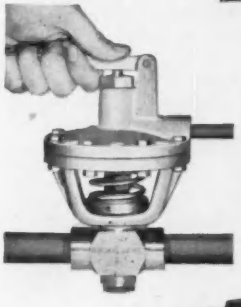


WHIFFLETREE OPERATOR

Two valves operated simultaneously by one operator. Valves may be globe or three-way and have a multitude of piping arrangements for mixing and routing applications.

AIR RATE INDICATOR

Top and bottom housing, 1¼" square anodyzed aluminum barstock, combination column studs and gauge protection. The ⅛" IPS ports may be relocated by removing column studs and rotating top or bottom housing. Standard calibration indicates 0 to 2 standard cubic ft. per hour of air. Other models available with built-in toggle actuated packless valves or needle type valves for precise control or special porting or additional ports to suit your requirements.



MANUAL RESET

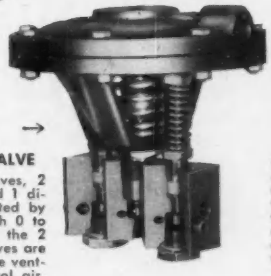
Wherever control air on dangerout or toxic process flows must be blocked for safety, on air failure until manually reset, these valves insure against disaster. Standard sizes ¼" and ½" I.P.S.

SAUNDERS VALVE, AIR OPERATED

Plastic valve, 2" and below, metal valve 1" and below. G. W. Dahl Co., Diaphragm Operators on these valves provide simple, sure automatic operation. Each application must submit full flow information.

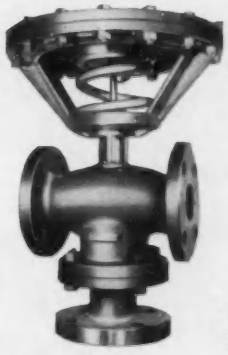
MINIATURE THROTTLING CONTROL VALVE, TOP MOUNTED MOORE POSITIONER

Compact, accurate rugged. High lift, positioning accuracy, low cost, and low in weight and size. Body, bonnet and blind head of barstock construction. Valve sizes up to 1", screwed or flanged. Trim Cv, 12.0 to 0.001. Pressures, 0 to 2000 psi. Temperatures, Minus 400 to Plus 1000°F.



BLOCK VENT VALVE

3 balanced valves, 2 reverse acting and 1 direct acting, actuated by one operator. With 0 to 3 psi control air, the 2 reverse acting valves are closed, center valve vented. At 6 psi control air, all valves closed. At 12 to 15 psi, the 2 reverse acting valves are open and the vent valve is closed, allowing free flow through body. Design pressure 1000 psi. *Teflon*, Chevron packing. *Teflon* seating for tight shut off.



DIAPHRAGM OPERATED 3-WAY CONTROL VALVE

Aluminum diaphragm operator, stainless steel body and trim, *Teflon* packing with *Teflon* seating for tight shut off. Available up to 2", flanged or screwed.

MINIMUM DISPLACEMENT PACKLESS VALVE

Designed specifically for minimum holdup in valving capillary tubing. 1¼" dia. body available with special bonnet for solenoid or diaphragm operation, or hand operation.

REPRESENTATIVES IN PRINCIPAL CITIES

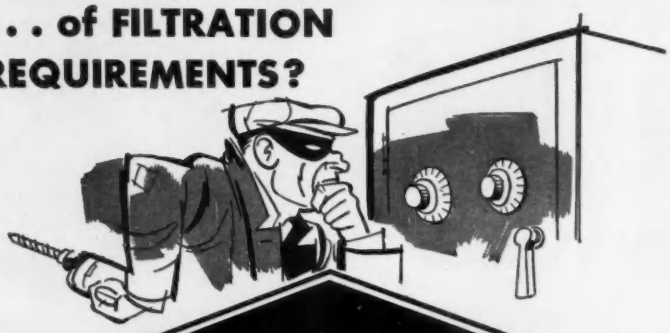
Write us for complete technical information, or for the address of our representative in your area.

GEORGE W. DAHL COMPANY, INC. 86 TUPELO STREET, BRISTOL, R. I.

VISIT OUR BOOTH 1562, I. S. A. EXHIBIT, CLEVELAND AUDITORIUM, SEPT. 9-13

Stopped by a TOUGH Combination...

...of FILTRATION REQUIREMENTS?

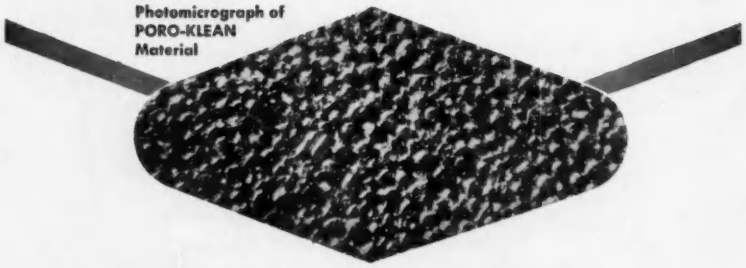


CUNO

PORO-KLEAN

THE POROUS STAINLESS STEEL MEDIUM THAT OFFERS YOU ALL THESE ADVANTAGES —

- **HIGH HEAT RESISTANCE** . . . permitting operation at temperatures as high as 900°F.
- **HIGH TENSILE STRENGTH** . . . up to 15,000 psi, allows Poro-Klean Filters to withstand differential pressures of more than 3500 psi and to handle extremely viscous liquids at relatively high flow rates.
- **HIGH CORROSION RESISTANCE** . . . allows the filtration of — or cleaning by — substances that would quickly damage other filter materials.
- **NO MEDIA DISCHARGE** . . . Cuno's unique manufacturing and control methods result in a much stronger material with *all* particles securely bonded at several points of contact. Independent tests have *proved* that Poro-Klean produces no product contamination due to media discharge . . . even under conditions of extremely high differential pressures and severe vibration.
- **UNIFORM FINE FILTRATION** . . . with standard material down to 5 microns. Material for sub-micronic filtration available on special order.



Photomicrograph of PORO-KLEAN Material

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CUNO ENGINEERING CORPORATION

2709 SOUTH VINE STREET, MERIDEN, CONNECTICUT

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EDGE-TYPE, WIRE-WOUND, FIBER CARTRIDGE and POROUS METAL FILTERS

Filtration Engineers in Principal Cities

been purchased by M-H for $4½ million, or just a little less than the price of two Datamatic systems (they start at $2½ each). Raytheon, which is expecting delivery of a Datamatic for its own use, emphasized that internal competition for its capital funds was the only reason for the transaction. Its business is growing as fast as Datamatic's, and it was simply a question of where to put the money.

This gives M-H full control of Datamatic. The first Datamatic system was to have been completed this summer; others are to follow in 1958, including one for M-H's own office in Minneapolis. In most cases they will go out on a rental basis.

The stock sale does not include certain advances by Raytheon to Datamatic to further the development of the electronic digital data-processing systems. These are repayable next year and the year afterward.

Robertshaw-Fulton Moves to Richmond, Elects Arden

News that Robertshaw-Fulton Controls Co. is moving its executive offices from Greenburg, Pa., to Richmond, Va., parallels the election of Thomas T. Arden as president and John A. Robertshaw as chairman of the board. Arden, formerly executive vice-president in charge of western operations, and Robertshaw, formerly president, join a new three-man executive committee headed by retiring Chairman Richard S. Reynolds Jr.

The new Richmond location is expected to yield better liaison with government agencies and departments involved in R-F's military work, improved communications with the company's eastern manufacturing divisions, and more convenient transportation facilities for personnel.

France Purchases REAC for Atomic Energy Studies

The French Commissariat a L' Energie Atomique has become the second organization to purchase a 400 REAC computer for use in nuclear research. The Reeves Instrument Corp. product is being installed in the Commissariat's Paris laboratories, hub of a program aimed at building and installing a number of prototype and research reactors in various parts of France. The French government, reticent about the specific role awaiting the REAC, says only that it will assist in "studies of new uses for atomic

By specializing in servo motors only—not systems—G-M gives you these advantages...

- A broader line of servo motors in sizes and types to meet a wide range of applications.
- Servo motors available in *all* the standard sizes.
- Standard sizes specially modified to meet specific circuit requirements—available on a quick-service basis.
- Creative engineering in designing special motors with special characteristics.
- Faster production—better service.

When reliability under extreme conditions is essential—specify G-M Servo Motors! G-M has long specialized in supplying precision servo motors to the Military Avionic Industry, especially designed to meet military specifications for humidity, salt spray, temperature, vibration and altitude. Whatever your needs, let G-M build a servo motor with the *right* characteristics to perform to your specifications.

Write *today for G-M charts, specifications, or consultation.*

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manufactured by the Components Division of

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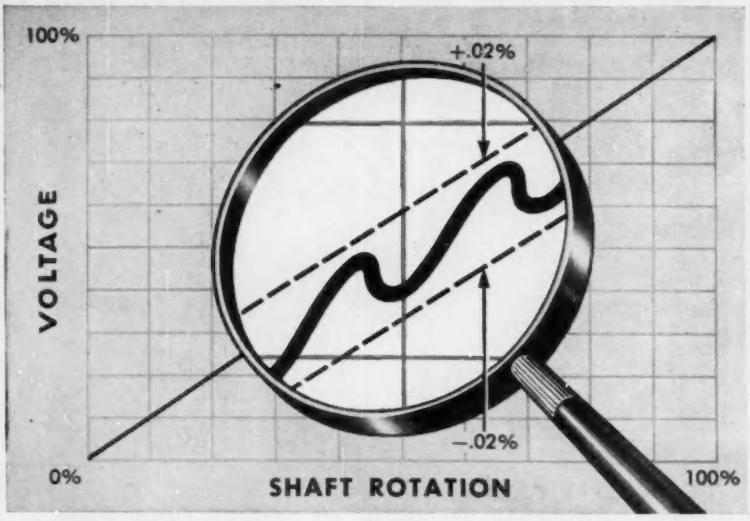


Potentiometer linearity and phase shift problems?

Chances are there is a Vernistat a.c. potentiometer that will solve them. The Vernistat potentiometer uniquely combines an accurately tapped auto-transformer with a linear interpolating resistance element. It has precise linearity, long-term stability, and low output impedance which minimizes loading error.

The Vernistat potentiometer is available in models with linearities as low as ±0.02% and output impedances as low as 45 ohms.

Check these specifications:

	Linearity	Output quadrature Maximum, 400 cps	Output impedance Maximum
Model 2B	±0.04%	0.50 mV/V	130 ohms
Model 2B1	±0.03%	0.13 mV/V	470 ohms
Model 2B2	±0.05%	0.47 mV/V	45 ohms
Model 2B3	±0.03%	0.16 mV/V	130 ohms
Model 2B4	±0.02%	0.06 mV/V	470 ohms

For additional information, write:

vernistat®
division

PERKIN-ELMER CORPORATION • Norwalk, Connecticut

WHAT'S NEW

energy". The first REAC purchased for this purpose is now being operated for the AEC by Union Carbide & Carbon Co. at Oak Ridge.

General Nuclear Engineering, AMF to Build 'Argonauts'

American Machine & Foundry Co. and General Nuclear Engineering Corp. have joined hands over a project calling for production of AEC-type Argonaut training reactors, the inherently safe units already being built in private-industry shops by the Nuclear Div. of Daystrom, Inc. (CtE, April, p. 50). Like Daystrom's design, the AMF-GNEC verison, to be called the "Educator", will go to universities and industry for training purposes. It is rated at 10 kw continuous duty.

AF Order Puts 'Snarks' on Northrop Delivery Line

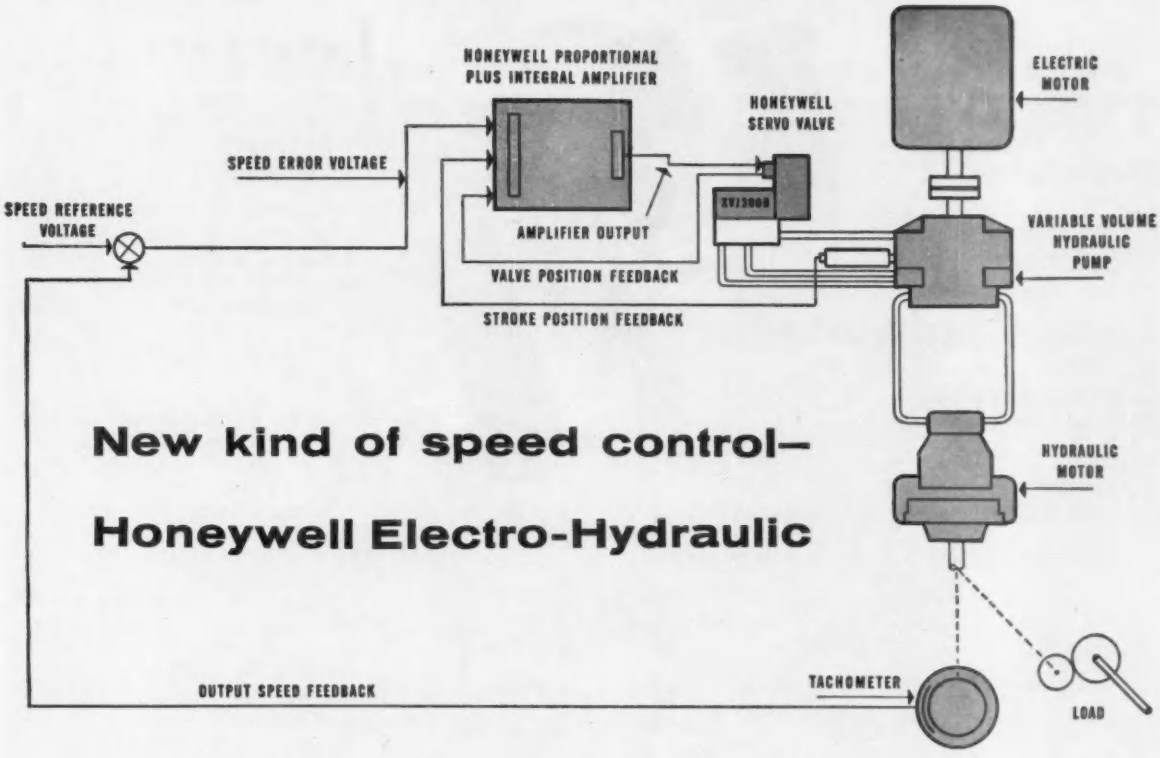
Delivery of Snark intercontinental missiles has been ordered by the Air Force. This means a $73-million production contract for Northrop Aircraft, Inc., builder of the 69-ft, nuclear-headed weapon. Northrop has 7,800 people working on the Snark program, most of them located at the Hawthorne, Calif., home of the Northrop Div. Missiles will be marked for operational units of the Strategic Air Command.

New Companies in the Field

Specialized Propulsion & Control Equipment Corp., to do instrumentation, design, and process work for the chemical and petroleum industries—in Dallas. One of "SPACE Corp.'s" first moves was to purchase the Engineering & Mfg. Div. of Shaw & Estes of Garland, Tex., a fast-growing Texas "control baby" (CtE, July, p. 59) making instrumented test facilities for jet and rocket engines.

Dynamic Research Corp., said to be one of the first companies devoted exclusively to inertial navigation—in Woburn, Mass. Three former members of MIT's Instrumentation Laboratory head the new systems and components design and development firm. They are: John S. Anderegg Jr., Howard R. Whitman, and Malcolm A. Douglas. Anderegg is DRC president.

Consulting Associates, whose prospectus practically covers the field (plant design, testing, high polymer



New kind of speed control—

Honeywell Electro-Hydraulic

Only an electro-hydraulic speed control system can give you all these advantages.

- Wide speed range—ranges of 1,000 to one are readily possible
- Smooth, steady, low-speed operation
- Fast response
- Negligible droop under load
- Infinitely variable speed control
- Easily adjustable speed

THE SPEED CONTROL diagram above is a typical example that shows the flexibility of Honeywell Electro-Hydraulic Control systems.

Honeywell servo valves and transistor amplifier combinations make new building blocks available for dozens of applications.

Rugged and dependable, they are smaller and more compact, have high speed of response, are easy to adjust and inexpensive to install.

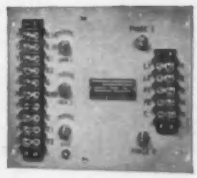
For complete information, including realistic delivery dates, call, wire or write Minneapolis-Honeywell Machine Controls Division, Dept. CE-9-210, Minneapolis 8, Minn.

Flexible building blocks to do the job

3-Way Valve (XVJ300)
Output Flow (no load)
100 psi—3.5 gpm
1000 psi—9.9 gpm

4-Way Valve (XVJ303)
Output Flow (no load)
100 psi—1.5 gpm
1000 psi—5.0 gpm

3-Way Valve (XVJ302)
Output Flow (no load)
100 psi—2.0 gpm
1000 psi—6.0 gpm



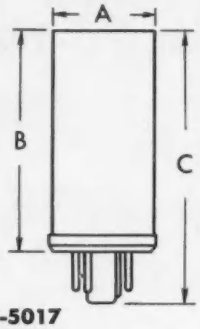
Amplifier (XRJ301)
Transistor Servo Amplifier
High gain, multiple input amplifier with superior reliability.

Honeywell

First in Controls

Full Wave SILICON Tube Replacement RECTIFIERS

Where dependability and ruggedness are a "must," Full Wave Silicon Tube Replacement Rectifiers will solve your problems. One of the four standard types described below will meet the requirements of your application.



S-5011
1N1150

Maximum Rating:

Peak Inverse Voltage per Section ..... 1600 Volts Max.
Peak Rectifier Current per Section ..... 8000 MA Max.
DC Output Current ..... 750 MA Max.
Ambient Temperature ..... 100°C Max.

Dimensions:
A—1-1/2" O.D. B—2-1/4" C—2-27/32"
Four Pin Base
Replacement for Types 80, 82, 83, 83V, 5Z3

S-5017
1N1237

Maximum Rating:

Peak Inverse Voltage per Section ..... 1600 Volts Max.
Peak Rectifier Current per Section ..... 8000 MA Max.
DC Output Current ..... 750 MA Max.
Ambient Temperature ..... 100°C Max.

Dimensions:
A—1-3/16" O.D. B—2-19/32" C—3-5/32"
Octal base
Replacement for Types 0Z4, 5X4, 5Y4, 6AX5, 6X5

S-5018
1N1238

Maximum Ratings:

Peak Inverse Voltage per Section ..... 1600 Volts Max.
Peak Rectifier Current per Section ..... 8000 MA Max.
DC Output Current ..... 750 MA Max.
Ambient Temperature ..... 100°C Max.

Dimensions:
A—1-3/16" O.D. B—2-19/32" C—3-5/32"
Octal base
Replacement for Types 5AU4, 5AW4, 5AZ4, 5T4, 5U4, 5V4, 5W4, 5Y3, 5Z4

S-5019
1N1239

Maximum Ratings:

Peak Inverse Voltage per Section ..... 2800 Volts Max.
Peak Rectifier Current per Section ..... 5000 MA Max.
DC Output Current ..... 500 MA Max.
Ambient Temperature ..... 100°C Max.

Dimensions:
A—1-5/16" O.D. B—3-3/4" C—4-5/16"
Octal Base
Replacement for Type 5R4

Send for data sheets on any of the above types.

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WHAT'S NEW

and coatings technology, economic and technical surveys, contract research, chemical processes, mechanical controls design, instrumentation, and formulation)—in Cleveland. Technical director is E. I. Arsan.

Moore Associates, which will develop, design, and produce telemetering equipment and accessories, including encapsulated carbonyl-iron inductors and r-f transformers—in Redwood City, Calif. President Laurence Moore most recently was project engineer at Levinthal Electronic Products, Inc. Before that he was chief engineer of Lectrolab Mfg. Others in the new venture: Albert L. Robinson, formerly with Bell Telephone Laboratories, and Felix Greene, a former official with the BBC.

Amphenol Great Britain, Ltd., organized to manufacture and sell aircraft, communications, and computer components carrying the label of Amphenol Electronics Corp. of Chicago—in Alperton, England. This makes Amphenol's second subsidiary. The first: Amphenol Canada, Ltd.

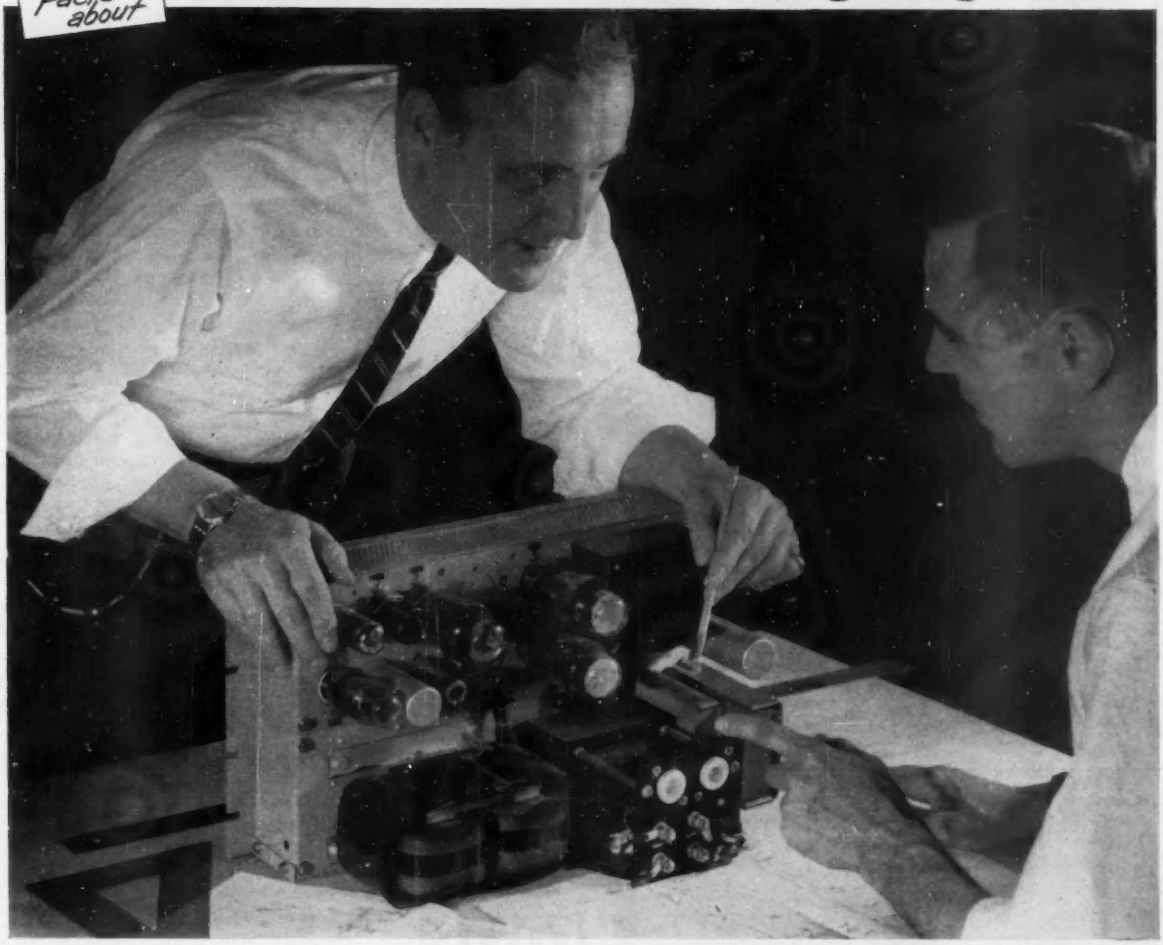
U. S. Semiconductor Products, Inc., to manufacture, and seek new uses for, silicon diodes, transistors, and rectifiers—in Phoenix, Ariz. Some of the unexplored possibilities for semiconductors, say the new company's officials, involve "natural" applications. Example: replacing of a 500-lb motor-generator set having 50-percent efficiency with a 3-lb silicon rectifier package that's 95 percent efficient. Scheduled for production so far are a low-powered, 100-mw silicon rectifier, a medium-powered, 1-2-watt diode, and a high-powered, 400-volt rectifier. President of USSP is Friedrich W. Schwarz, one of Germany's wartime V-2 experts. With him are: Robert S. Rutherford, a former research man at the Air Force's Cambridge Research Center; Milton R. Sherman and Peter H. Robeck, both formerly with Motorola, Inc.; Glenn W. Skouson, who was with the AEC at its Pacific Proving Grounds, and Elling H. Runden, formerly chief engineer for Accurate Spring Mfg. Co., Chicago.

Rheem-Solartron, Ltd., formed by Rheem Mfg. Co. and the Solartron Electronic Group, Ltd., of England, to do R&D work in electronics. Collaboration by Rheem and Solartron will center on such things as radar simulation and a multi-headed reading machine for commercial applications.

Telemetering Corp. of America, whose officials announce they are out to improve and simplify systems for

Facts about

STABILINE® *Automatic* Voltage Regulators



STABILINE type IE (Instantaneous Electronic) is available in 115 volt units — input range from 95-135v. and 230 volt units — input range from 195-255v. STABILINE type IE5101R shown above.

"Here's how to Build-in Automatic Voltage Regulation"

"No matter how good your control instrumentation is, it is not going to be precisely accurate at all times unless the input voltage is precisely *constant*.

"You just can't get better automatic voltage regulation equipment than with this STABILINE. At no load, full load or any intermediate stage it maintains constant *output* voltage regardless of line fluctuations.

"This sensitive, yet ruggedly constructed, automatic voltage regulator is a must component in today's voltage sensitive apparatus."

Three types of STABILINES are available for individual needs:

Type IE (*Instantaneous Electronic*) is completely electronic, instantaneous in action, with no moving parts. Constant output voltage is maintained regardless of line or load fluctuations.

Type EM (*Electro Mechanical*) has zero waveform distortion. Insensitive to magnitude and power factor of the load. Highly efficient.

Type TM (*Tubeless Magnetic*) has no moving parts . . . no tubes . . . no transistors. Ideal for unattended locations or where failure can never be tolerated.

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City ..... *Zone* ..... *State* .....

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ADJUSTMENT
on this
AGASTAT®
time/delay/relay

Frequent time adjustments are no problem with the dial head available on AGASTAT time/delay/relays. They provide a complete range of adjustment with 1 revolution of the dial. Dial markings permit easy calibration for accurate adjustment. And you can spot each of the 4 timing ranges quickly because they are color coded: blue from 30 seconds to 15 minutes; red from 10 seconds to 2 minutes; yellow from 0.1 to 10 seconds; white from 0.1 to 3 seconds.

Like all AGASTAT relays, units with dial heads are solenoid actuated, pneumatically timed. Each model is available with either dial head or needle valve adjustment. Where frequent readjustment of timing is necessary, dial head adjustment should be specified. For bulletin on all popular AGASTAT time delay relays, write to: Dept. A28-920.

AGA DIVISION
Elastic Stop Nut Corporation of America
1027 Newark Avenue, Elizabeth, New Jersey
Pioneers in pneumatic timing

NEW MULTI-PURPOSE DIGITIZER
for precision voltage measurement

Franklin
Model 310A
Digitizer

COSTS
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provides fast, accurate readings

In the laboratory or on the production line, this all electronic, multipurpose digitizer is ideal for use as an analog to digital converter, voltmeter or data reduction element. Measuring voltages from 000.0-120.0 volts DC, it provides accuracy of 0.1% of full scale and speed of 60 readings per second, automatically or on command . . . heretofore unobtainable at this low cost. Coded outputs of each significant figure in the visual readout provide a signal source to operate matrices, printers, punches, or categorizing equipment.

Also available–special DC amplifiers which convert very low voltages (microvolt ranges) to levels useable by the Model 310A Digitizer .

FEI
Franklin Electronics, Inc.
BRIDGEPORT, PA.
Electronic & Nuclear Development & Manufacturing

WHAT'S NEW

transmitting instrumentation data in forms readily usable by the computers of the future–in Los Angeles. To be investigated are remote metering of pipe-line information for oil companies and public utilities and the application of telemetry in the conservation of natural resources(monitoring their quality and quantity in remote areas). William A. Cooke, formerly with Audio Products of Los Angeles, is president, and Hugh F. Pruss, most recently chief engineer of the Telemetering Div. of Federal Electronics Corp., is vice-president and chief engineer.

Daystrom, Ltd., which will handle sales, service, assembly, and manufacture of Daystrom electronic products in Canada–in Toronto.

New Divisions and Groups

An "American Center for Analog Computing", the latest consulting activity of **Pi-Square Engineering Co., Inc.**, of Boston. Major areas of interest will be design problems in control systems, dynamics of machinery, and posers in hydraulics, pneumatics, electronics, and biology.

A new department formed by **Magnetic Research Corp.** for the development and manufacture of magnetic servo systems for remote indication, measurement, recording, and control. Department supervisor is C. T. Kleiner.

A DataTape Div., organized by **Consolidated Electrodynamics Corp.** to engineer, design, and manufacture a standard instrumentation line of magnetic-tape recording and reproducing equipment. Division officers include: Philias H. Girouard, formerly assistant director of engineering, director; Herbert Karsh, chief engineer; and Burt W. Cobb, manager of manufacturing.

An Electronics Div. of **Sperry Rand Corp.** at Clearwater, Fla., to accommodate the company's expanded operations in new microwave and electronic instrumenation for aircraft and missile systems and industrial processes. Rudolf E. Henning is director of technical operations.

An R&D center, billed as the most advanced in the west, established by **Aerophysics Development Corp.** at Santa Barbara, Calif. The center, and an adjoining engineering building, are the first two units of a planned five-unit building program to cost more than $5 million.

An Industrial Products Div., which, as a result of reorganization talks at

Want a standard power reactor from 50 to 2000 watts? Put your finger on CONTROL

No need to put up with extra costs for special design of saturable reactors. No reason for waiting for special units to be designed to meet your individual requirements. CONTROL offers two complete lines of power reactors. You pick them from our catalog. We take sub-assemblies from our shelves, add control windings to your specifications, and deliver complete units—fast.

CONTROL reactors are ready in eleven sizes in both 120 and 240 volt ranges. Our unique catalog R-10 gives you complete physical and operating characteristics. It tells you, for instance, that six ampere-turns control nearly 2,000 watts in the largest size, and that only two ampere-turns are needed for the 50-watt smallest size, illustrating the extremely high gain of these units.

Want to know about cut-off ratios? CONTROL reactors run at least 40 to 1. Want to know about construction? Cutaway shows you the tough, rugged design that insures "forever" operation with no servicing or maintenance, if operation is normal.

Yes, there's a real improvement here for harassed engineering departments. Standardization means reliability and quality at a competitive price. Write for Catalog R-10 today and read all about it. *CONTROL, Dept. CE-42, Butler, Pennsylvania.*

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WHAT'S NEW

International Telephone & Telegraph Co., will take on the electronic instrument manufacturing and distribution chores of the Instrument Div. of the subordinate **Federal Telephone & Radio Co.** Headquarters for the new organization will be at Clifton, N. J. Rudolf Feldt, its vice-president, is in charge there.

A Hydraulic Valve Div., formed by **Hydraulic Accessories Corp.** of Van Dyke, Mich., to handle valve production on a precision basis.

A Reliability Assurance Section, which will oversee reliability of products going to the military services from **Electronic Communications, Inc.** Said to be one of the first sections in industry to be concerned exclusively with reliability, it will be staffed by 40 scientists and technicians from the following groups: test equipment, qualification testing, component evaluation and reliability, and environmental testing. G. Wendell Carr, formerly head of test engineering, will be at the helm.

An Electro-Mechanical Dept. for **Hoffman Laboratories, Inc.**, to manufacture specialized electromechanical gear for missiles and navigation systems. Specific products already planned: servos, gyroscopes, inertial platforms, navigational apparatus, fire-control systems, and precision mechanical components. Laurence Mendelsohn, formerly at MIT's Instrumentation Laboratory, joins Hoffman as a vice-president.

A Systems Div. to handle **Collins Radio Co.'s** expanded operations in communications systems. The company expects to go into single sideband and data transmission systems to complement its work in microwave and trans-horizon systems; in furnishing them, it does everything from the design work to the construction of access roads and buildings. John D. Nyquist, formerly director of manufacturing at the Cedar Rapids, Ia., home office, is the new division's executive director. Two new directors of systems engineering have been named to work with him: Frank C. Dyer at Dallas and Richard M. Ringoen at Cedar Rapids.

A Neutron Physics Section in the Atomic & Radiation Physics Div. of the National Bureau of Standards, under Randall S. Caswell, who was a professor of physics at the University of Kentucky and a physicist at Oak Ridge National Laboratory before joining the Bureau in 1952.

A Production Test Dept. to keep up with increased activity on produc-

Coffee-break Reading—

IF you are responsible for (or are engaged in) the design, development, purchase or production of systems requiring precision timing, you realize the distinct advantage of knowing about the companies from which you buy. The background, experience, reputation of these suppliers and the application of their products can, as you know, act as a valuable guide in saving time and money, — not to say the avoidance of regret and disappointment.

- So, over your coffee cup, know ye that: —
- Our products consist basically of frequency standards and precision, electronic forks, (50 to 3000 cycles, accuracy to 1 part in 100,000 or better if required). These are available separately for integration with units of your own manufacture or as parts of instruments made by us.
- Several of our executives have engaged in the engineering of these frequency standards and precision forks for more than 20 years; a few more are at the 15-year mark. During this time we have learned much regarding the subtle idiosyncracies of materials and the mischievous capers of delicate processes. Each of our completed production units undergo 85 measurements. A single transistorized standard contains copper, steel, nylon, silicone rubber, glass, carbon, teflon wire, mylar capacitors, silicon diodes and a fork alloy containing 15 elements. So what? Accuracy, dependability, stability . . . superiority.
- In miniaturization, our staff has produced units which, in a 5-ounce, 6-cubic inch volume have proved more rugged and possess efficiency superior to 60-pound, 3-cubic foot units in general use some years ago.
- Our company has been in the frequency standard business for 20 years. Instruments of our manufacture have met the rigid inspection and exacting tests imposed by governments, the armed forces and industry for widely varied, high-precision timing applications. Continuing reorders and our consequent growth attest the satisfaction of our products.

REPRESENTATIVE FIELDS OF APPLICATION

Aviation, Navigation
Ordnance, Ballistics
High-speed Photography
Viscosity Measurement
Fluid Flow
Nuclear Physics
Telemetering
Chemical Reaction
Radiation Counting
Computers
Facsimile
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Accurate Speed Control
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INDUSTRIAL COUNTING AND CONTROL INSTRUMENTS

COUNTING STRIP

- STANDARD COUNTERS — hundreds of models . . . preset counters and totalizers.
- SPECIALIZED COUNTERS — modular construction permits reasonable prices.
- PLUG-IN STRIPS — to use in your own applications. Low heat, long-life counting tubes and conservative design provide:

Reliability in use — over a year in constant operation without any servicing has been reported by satisfied industrial customers.

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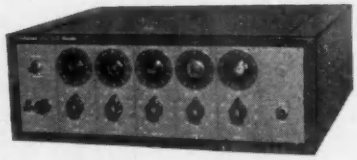

For information on various inputs, outputs, and counting units (up to 20,000 counts per second) . . . write for Industrial Bulletin — Edition II.

Sales Representatives in principal cities.

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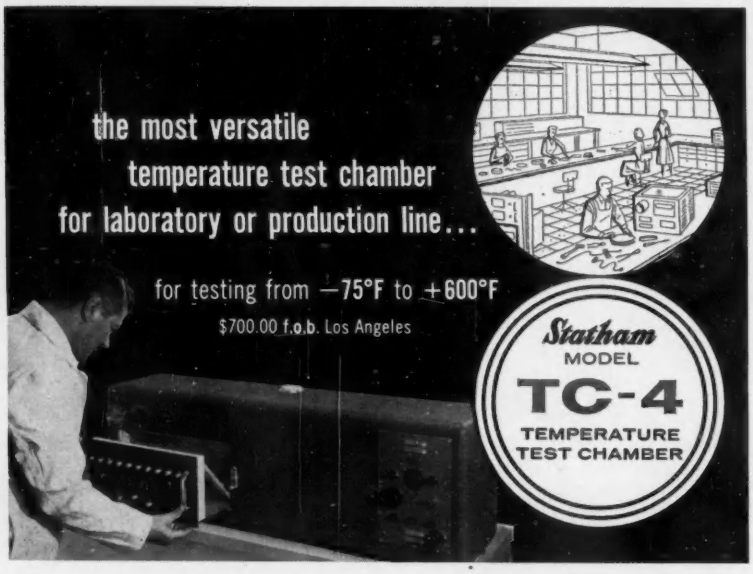


The Statham Model TC-4 portable Temperature Test Chamber has proven its versatility and value for years in such fields as the Aircraft, Electrical, Electronic, Automotive, and Chemical industries. Its wide operating range—from −75°F to +600°F makes this unit the ideal solution for ambient temperature tests in the *Laboratory* or on the *Production Line*. Accurate and adjustable control, wide temperature range, and a product capacity of 600 cubic inches provide the most versatile test chamber available for your testing needs. Interchangeable extra trays may be ordered for greater convenience and elimination of loading delays.

Write for descriptive literature on this and other models, or wire or call for prompt reply on your application.

Statham
DEVELOPMENT CORPORATION
12411 West Olympic Boulevard,
Los Angeles 64, California
GRanite 7-9157.

WHAT'S NEW

tion of commercial and military microwave products made by **The Narda Corp.** Until recently the department was part of the engineering laboratories; an upswing in UHF and microwave manufacturing is mainly responsible for its new status.

Fattenings

Anders-Lykens Co. of Lykens, Pa. (instrument air dryers and gas dehydrators) by **Milton Roy Co.,** which will operate A-L as a division under Director Edward Anders, founder. Headquarters will be at Milton Roy's Philadelphia office.

Electric Switch Corp. of Columbus, Ind. (Staley metallic mercury switches) to **Bernco Engineering Corp.** of Indianapolis.

CG Electronics Corp. of Albuquerque (radio-control equipment) to **Gulton Industries, Inc.**

Fusions

Philips Electronics, Inc., a subsidiary of Philips Industries, Inc., with **A. Hollander & Son, Inc.,** both of Delaware.

Simplex Engineering Co., Inc., of Zanesville, Ohio, with **Racine Hydraulics & Machinery, Inc.,** of Racine, Wis.

Reliance Electric & Engineering Co. of Cleveland with **Master Electric Co.** of Dayton.

Other Developments

North American Instruments, Inc., has changed its name to **Northam Electronics, Inc.**

Consolidated Electrodynamics Corp. has changed the name of its Electronic Industries Div. to Alectra Div. "to eliminate confusion caused by the existence of several other companies with names similar to Electronic Industries."

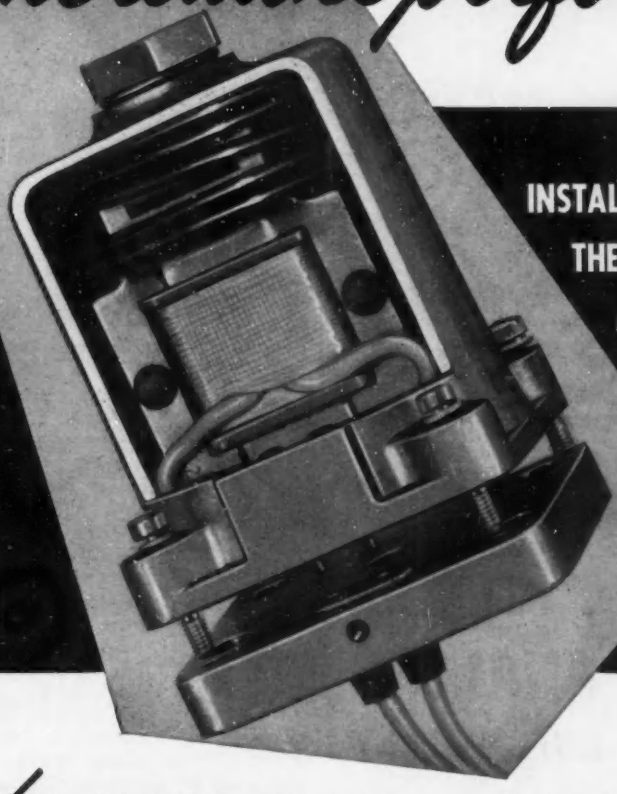
New Buildings

A standards laboratory for testing and certifying master mechanical and electrical measuring devices, for **International Telephone & Telegraph Corp.** in Clifton, N. J.; a precision optical shop for **Perkin-Elmer Corp.** in Norwalk, Conn.; western district offices to give better service to West Coast customers of **Applied Science Corp.** of Princeton; new headquarters at Santa Ana, Calif., for **Electronic Engineering Co.** of California.

Larger offices in Westbury, N. Y., for **Universal Transistor Products**

Decco OIL-IMMERSED SOLENOIDS

give incredible performance



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SEALED IN OIL. Each unit is sealed in its own, contamination proof, oil filled, die-cast housing. A convenient, plug-in base allows split-second replacement in case of change in power requirements. Heat dissipation and wear control reach a new level of efficiency in these units.

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WHAT'S NEW

Corp.; a $2-million addition to **Stanford Research Institute's** Menlo Park, Calif., facilities; an R&D center at College Point, N. Y., for **Belock Instrument Corp.**; an enlargement of facilities at Pasadena, Calif., by **Burroughs Corp.'s** ElectroData Div.; expansion at Boston, Mass., by **Datamatic Corp.**

A manufacturing plant to house the fabrication activities of **Collins Radio Co.**, in Cedar Rapids, Ia.; another (the fourth) laboratory at Palo Alto, Calif., for the R&D center of **Lockheed's** Missile Systems Div.; a home (manufacturing, R&D, sales, and administration) for **Minneapolis-Honeywell's** Valve Div., in Fort Washingington, Pa.

Contracts in Control

• **General Services Administration**—Transistorized radiation detectors and dosimeter-pen chargers ($863,790) to Universal Transistor Products Corp.

• **Army**—Navigation and flight-control systems for the L-20 de Havilland Beaver and the Sikorsky H-19 helicopter ($1.5 million) to Ryan Aeronautical Co.

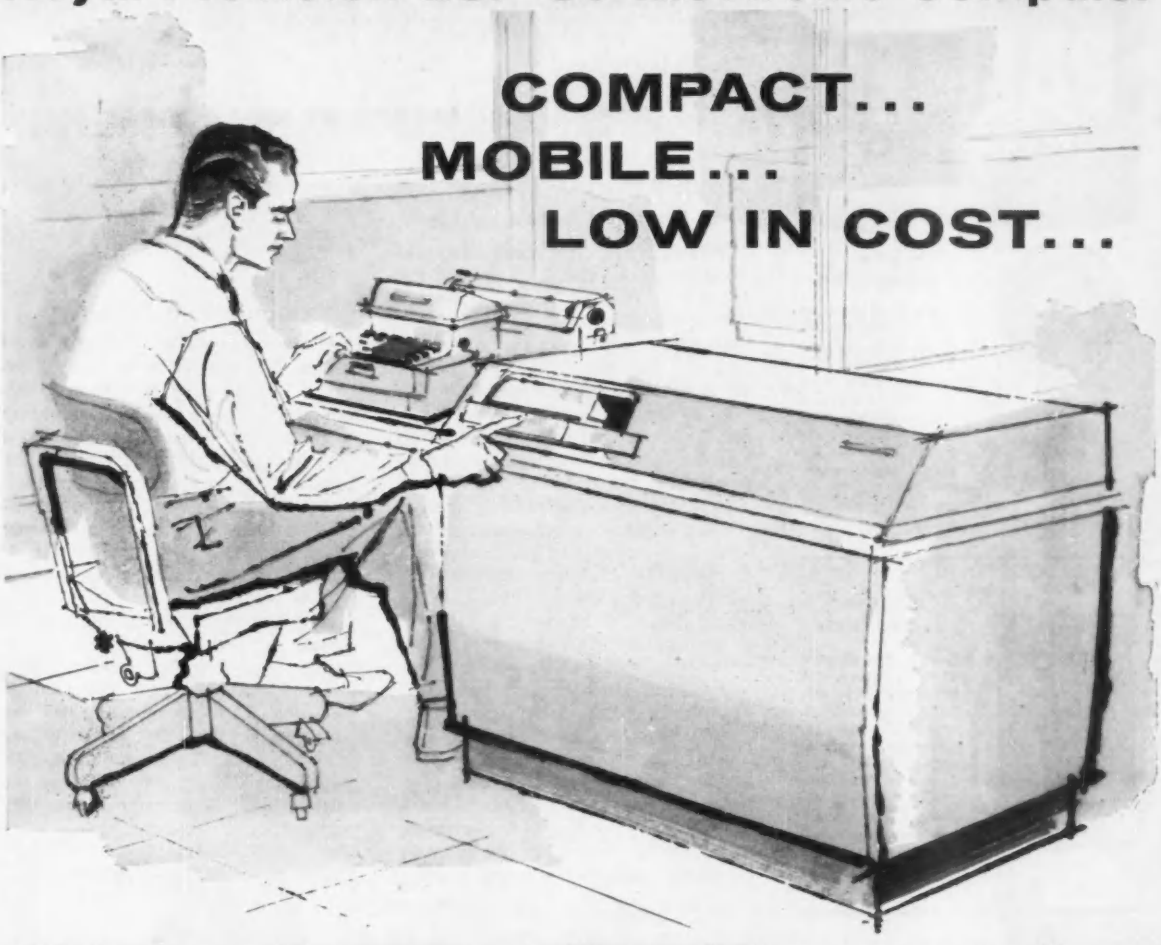
• **Air Force**—Course indicator aircraft instruments ($1,212,586) to Daystrom's Weston Electrical Instrument Corp.; axis-damping systems for the Lockheed F-104 Starfighter ($5 million) to Lear, Inc.; electronic test and check-out equipment for missile ($9 million) to Siegler's Hallamore Electronics Div.; a digital position-readout system to prepare inputs for large-scale digital computer (value undisclosed) to Wayne-George Corp. of Boston; a year's extension of its ram jet engine flight-test program ($14.5 million) to Lockheed.

• **Navy**—An experimental launching system for the 1,500-mile-range Polaris missile ($10 million) to Westinghouse Electric Corp.

• **Civil Aeronautics Administration**—Monitoring and control equipment for tactical air navigation (TACAN), part of the VORTAC system of short-range navigation ($10 million) to Stromberg-Carlson Div. of General Dynamics Corp.

• **Others**—Vibration simulation system for missile and jet components ($221,000) to Ling Electronics, Inc., from Convair; airborne navigation on systems (more than $1 million) to General Precision Laboratory, Inc., from The Martin Co.; electronic servo computers for a Navy radar system ($400,000) to Beckman's Helipot Div. from Hughes Aircraft Co.

Royal Precision LGP-30 Electronic Computer



high-speed computation right at your desk

The result of 20 years' experience in the design of electronic computers, LGP-30 puts you in complete control of your own engineering problems. Used right at your desk, LGP-30 allows you to program your own material without planning in detail. You modify equations on the spot, follow your work to completion. Thus, you eliminate much detailed calculation . . . uncover added time for creative engineering.

Ease of operation. LGP-30's simple command structure offers the same complete internal programming found in computers many times its size and cost. Internally binary, serial, single address . . . LGP-30 enters and reports alpha-numeric information by punched paper tape or keyboard.

Greatest capacity in price range. The most powerful stored program computer of its size yet developed, LGP-30 has a magnetic drum "memory" of 4096 words. Fully automatic, it performs sub-routines . . . executes self-modifying programs.

Exceptional flexibility. LGP-30's wide range of applications includes double precision abstractions; compiling and diagnostic routines; 3-address interpretive routine with floating point abstractions; matrix operations including inverting and Eigen value problems; basic trigonometry and log functions; square root and roots of polynomials.

Nation-wide sales and service. Detailed analysis of your requirements is available through Royal McBee's nation-wide staff of trained applications engineers.

Outstanding features of LGP-30

- **Operates from regular wall outlet (110 volts AC).**
- **No expensive installation . . . no external air conditioning.**
- **Unusually large "memory"— 4096 words.**
- **Word length: 32 bits, including sign and spacer bit.**
- **Average access time: 8.5 ms.**
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- **Lowest cost ever for a "complete" computer.**
- **Nation-wide sales and service.**

For further information, write Royal McBee Corporation, Data Processing Equipment Division, Port Chester, N. Y.

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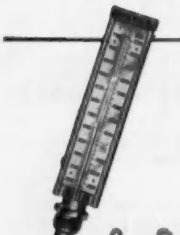

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IMPORTANT MOVES BY KEY PEOPLE

Missile Designer Takes Over Young Electronics Dept.

The man who has taken charge of the year-old Electronics Dept. in the Hamilton Standard Div. of United Aircraft Corp. holds 12 patents in automatic control, has 28 more pending, and has been the key figure in the design of guidance systems for at least two missiles. But that's not all. Robert Main, who comes to Hamilton Standard from Stavid Engineering, also was in charge of development of a complete missile control program.

Main's principal area of interest has been radar and missile guidance. After a period as research engineer for Robertshaw-Fulton Controls Co., he joined American Machine & Foundry at Boston, and it was here that he directed development of a guidance system for the Army version of the Terrier missile. Later, as operations manager in charge of electronics for The Martin Co., he piloted design of a $100-million program for missile control. And most recently, as director of R&D for Stavid, he led work on the guidance device for the Regulus II, as well as on an airborne homing control radar system. He is a senior member of the IRE.

His new assistant manager is George I. Willis.

Other Important Moves

▶ **Abraham Fuchs,** the new head of the Analytical Dept. of CDC Control Services, Inc., comes from Westinghouse Electric Corp., where he was a senior engineer in the Air Arm Div. He also was an engineer at the Bendix Aviation Research Laboratory. Fuchs has had extensive experience in the synthesis of high-performance servos and is the author of many papers on the theory and application of control systems.

▶ **Robert Beck** leaves the Bendix Computer Div., where he was in charge of the digital computer section, to become chief engineer of Packard-Bell Electronics Corp. At Northrop Aviation, Inc., where he was located before joining Bendix, he helped develop the Maddida special-purpose digital computer. As chief engineer, Beck will work closely with **Max Palevsky,** director of an R&D project aimed at development of a

Robert Main

Abraham Fuchs

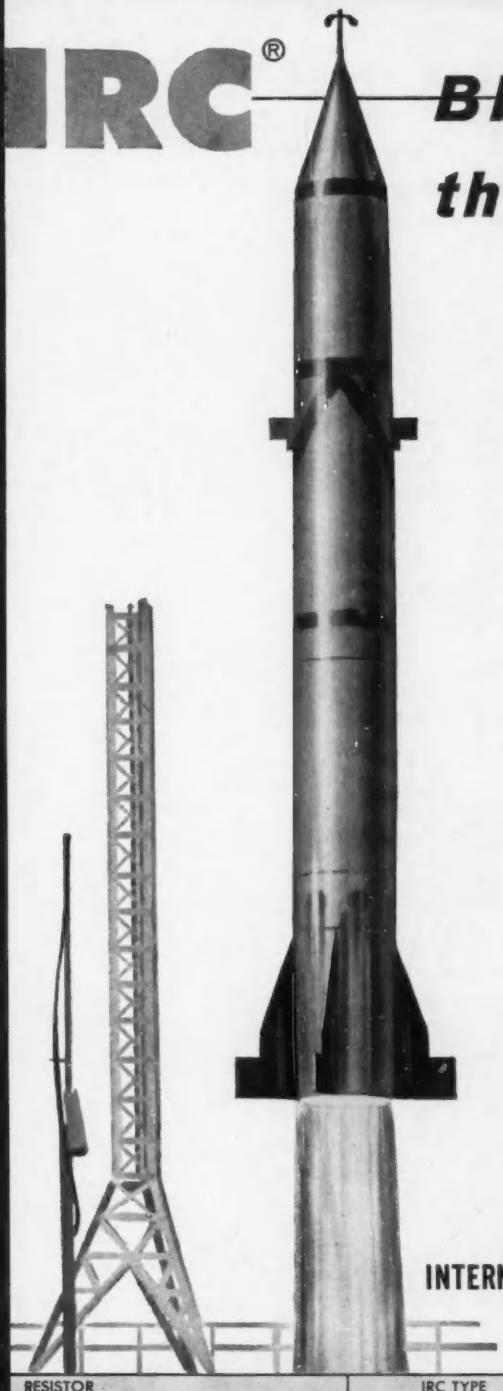
Robert Beck

S. C. Spielman

Don Jenson

E. F. Conklin

IRC® BREAKS THROUGH the reliability barrier



As jet planes and missiles leave old barriers behind, electronic components find ever-tougher barriers of reliability ahead of them. Those designed for yesterday are already obsolete, those designed for today will soon be. But IRC resistors are ready now to leap ahead of tomorrow's new barriers. Designed ahead of their time, they are also produced by "ahead of their time" processes and quality control techniques. This pattern of progress makes IRC reliability a standard unto itself—a standard that is yours on the widest range of electronic components in the industry.

There is nothing theoretical about the IRC standard of reliability. In most of the major avionic progress-projects, it is being proved out by rigorous field tests. It is also apparent in the way IRC resistors withstand extreme temperature, humidity, and mechanical conditions. It is evident, too, in resistance to shock and vibration . . . in improved shelf life . . . in the way IRC resistors consistently surpass MIL spec requirements.

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Fixed Composition	BT	RC	MIL-R-11B	B-1
Fixed Wire Wound (Low power)	BW	RU	JAN-R-184	B-5
Fixed Wire Wound (High power)	PWW	RW	MIL-R-26C	C-1
Fixed Wire Wound (Precision)	516L 316A	RB17 RB52	MIL-R-93A MIL-R-93A	PH
Meter Multiplier (Sealed precision)	MF	MF	JAN-R-29	D-2
Deposited Carbon	DC	RN	MIL-R-10509B	B-4
Deposited Carbon (Molded)	MD	RN	MIL-R-10509B	B-9
Boron Carbon	BC	RN	MIL-R-10509B	B-6
Boron Carbon (Molded)	MB	RN	MIL-R-10509B	B-8
High Frequency	MP HFR	RF RF50	MIL-R-10683A MIL-R-10683A	F-1

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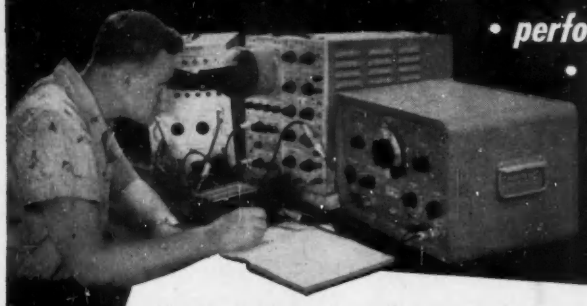

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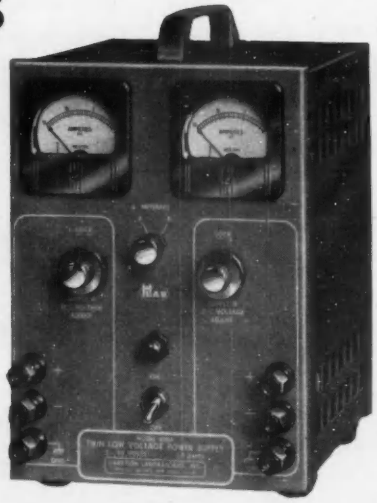

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WHAT'S NEW

high-speed digital computer for the Army Computation Center at Redstone Arsenal, Huntsville, Ala.

▶ The new director of engineering for Philco Corp.'s Governmental & Industrial Div. is **Sterling C. Spielman,** who was director of electronic engineering in the division since 1951 and chief engineer in charge of TV receiver design before that. He joined Philco in 1933. **Frank D. Peltier,** named director of engineering planning, will assist him.

▶ Chemtrol Corp. has named **Don Jenson,** a veteran of design and engineering projects involving pressure vessel work and piping systems, chief engineer. His previous affiliations include Standard Steel Corp. of Los Angeles, the AEC, and Carrier Corp.

▶ Lear, Inc., has transferred **Edward F. Conklin,** manager of the Grand Rapids (Mich.) Div., to Santa Monica, Calif., where he takes over the LearCal Div. in the same capacity. At Lear Cal there are 700 employees working on radio communications, navigation, and flight-control devices.

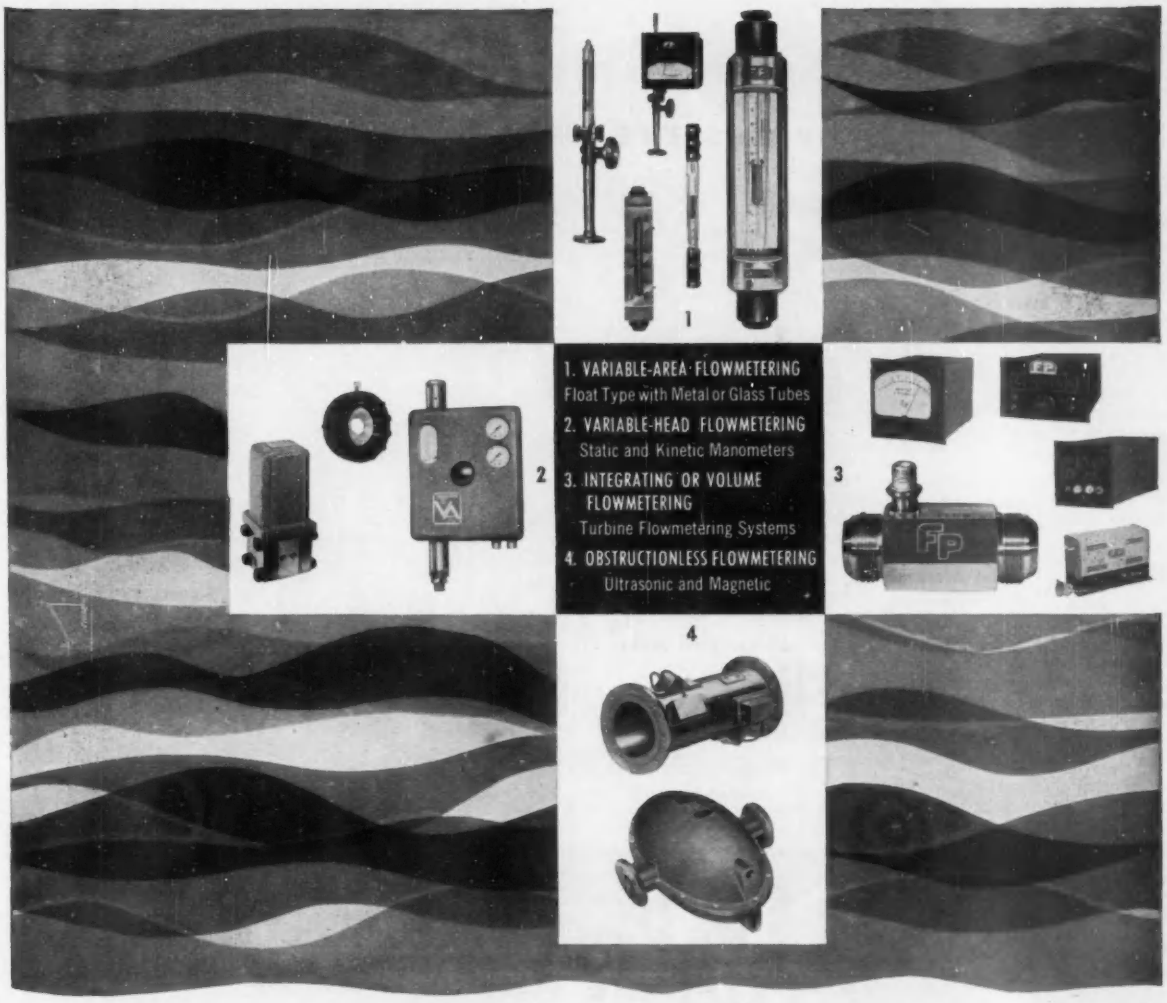
▶ As chief industrial engineer of ESC Corp., **Edward J. Thomas** will supervise production of delay lines, pulse-forming networks, and related equipment. His previous experience was with International Telephone & Telegraph Corp. and Electronic Transformer Co. of New York.

▶ Two key spots in Consolidated Electrodynamics' Alectra Div. have been filled by **Willard T. Holmes,** named director of engineering, and **Roy K. Stephens,** who replaces him as director of manufacturing. Holmes has held important posts with Traid Transformer Mfg. Co., Tetrad Co., Inc., Tartak Electronics, and Electronic Industries, Inc., the recent Consolidated acquisition which became the Alectra Div. Stephens, most recently head of the Printed Wiring Dept., has been with Cee-Bee Chemical Co., Construction Laboratories, Inc., and Convair.

W. T. Holmes

R. K. Stephens

▶ Newly appointed by Beckman Instruments, Inc., are **Robert M. Ward,**



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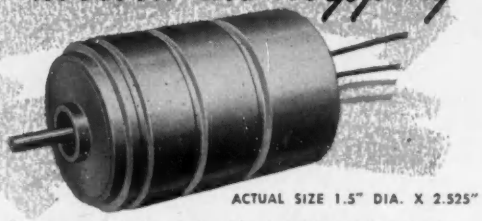
NEW! Syncramental motor provides precise bi-directional stepping



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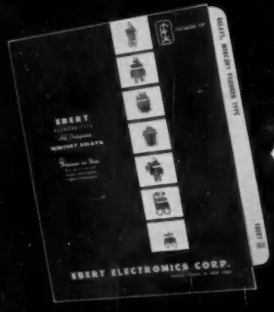

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WHAT'S NEW

manager of the Berkeley Div.; **Thomas Scatchard** and **John Pamperin,** directors of manufacturing at the Berkeley and Helipot divisions, respectively; and **Ray St. Onge,** product instrument manager at the Process Instruments Div. Ward, formerly division manager for Thompson Products, Inc., was with that company for 16 years; Scratchard, formerly Berkeley's plant manager, came to Beckman in 1956 from Marchant Calculators, Inc.; Pamperin, who will have charge of the Helipot plants in southern California and Toronto, moves into his new post from that of factory manager for Helipot; St. Onge is a former Beckman field engineer.

R. M. Ward

John Pamperin

▶**Archie F. Boscia,** named chief product engineer for Cohu Electronics' Kin Tel. Div., comes from Stromberg-Carlson, where as section head of communications and navigation he supervised production of airborne units for the Tacan system.

▶**William R. Hough, Walter H. Haber,** and **Hugh D. Luke** have been elected vice-presidents for operations, and **Richard A. Geuder** has been elected vice-president for marketing by Reliance Electric & Engineering Co. All four positions are brand new. At the same time, **Earl C. Barnes** becomes chief engineer, **Jay W. Picking** manager of the Control Div., **Karl H. Meyer** manager of manufacturing services, **Don E. Bouffard** manager of manufacturing in the Ashtabula Div., and **Jonathan L. Collens** and **Ralph G. Davis** assistant managers at the Ivanhoe and Ashtabula divisions, respectively. Hough, who stays in as vice-president for engineering, a post he assumed in 1948, is a former Reliance chief engineer. Haber and Luke are managers at Ashtabula and Ivanhoe (Cleveland), respectively. Geuder was named general manager for marketing last March. Barnes, assistant chief engineer for the past year and a half, joined Reliance in 1940; Picking, a 30-year man, formerly was manager of engineering in the Control Div; Meyer, who came to Reliance in

Passive INFRARED Systems End Need for Visible Light in Photomapping Objectives; Concentrations and Operations Show Through Concealment.

A lone photo-recon plane, slipping over New York one dark night in 1951 made this graphic shot of ground activity on the familiar island. And, had it been under **total** black-out conditions . . . the picture would be the same.

For this scene was not made with visible light; it is an infrared photo of the heat concentration on the ground—a dead give-away of the location of people, working machinery, vital installations.

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Any time a plane can get through to a target area, it can shoot a highly informative picture. Installations and concentrations of personnel show up sharply and vividly. Dispersion and concealment do not provide protection against passive infrared reconnaissance.

Infrared radiation is an exceedingly effective medium for detection—almost impossible to jam, mask, or conceal. It is an inevitable function of heat, becoming more intense as energy output grows. Passive infrared detecting devices do not reveal their own location in any way.

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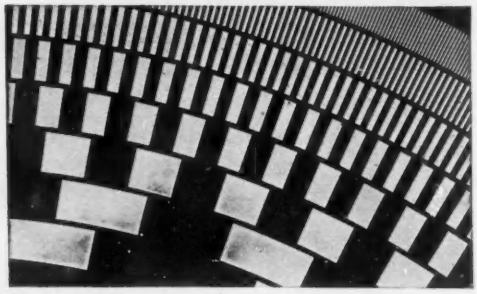
Gurley Standard Binary Code Discs Now Available in Four Versions



Gurley, manufacturer of the *standard* binary code disc for the electronics industries, is now able to supply four versions for use in either photo-electric, magnetic or contact types of pickups.

Containing concentric zones of information in the gray (reflected) code, the Gurley discs contain alternate clear and opaque sectors. Thin annular rings separating adjacent zones are opaque. Varying patterns record up to 8192 bits of information (65,536 on special designs!).

Four coatings are available: "Type T"—photoengraver's glue with colloidal (black) silver, essentially grainless; "Type R" with etched metal coating, for reflectivity and transmission contrast; "Type M" with chemically deposited ferrous alloy possessing both *magnetic* and optical transmission contrast; and "Type C"—metal bonded on glass for electrical *contact* use as well as in contrast of optical transmission. WRITE FOR BULLETIN 7000.

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- Ball bearing construction throughout — super precision ball bearings in spindle
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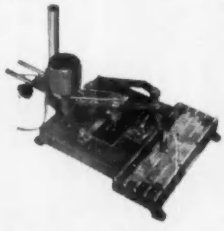
- Vertical range over 10 inches

MODEL 106 PORTABLE BENCH MODEL- 2- OR 3-DIMENSIONAL



- 40 pounds of unbeatable speed and accuracy at a reasonable price
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GREEN INSTRUMENT CO., INC.

395 Putnam Avenue Cambridge, Mass.

WHAT'S NEW

1926, moves up from manager of manufacturing at Ivanhoe; Collens advances from superintendent there; Bouffard most recently was industrial engineer at Ashtabula, and Davis was manager of manufacturing in the Control Div.

▶ Bolt Beranek & Newman, Inc., engineering psychologists and noise and vibration control specialists of Cambridge, Mass., has brought in **J. C. R. Licklider** from MIT, where he was associate professor of psychology, to direct its Dept. of Engineering Psychology. At the same time **Karl D. Kryter,** director of the Operational Applications Laboratory of the Air Research & Development Command, joins the BB&N department to work under Licklider. Both men are psychologists with PhD's from the University of Rochester and have dealt at length with problems involving the handling, communication, and processing of information by humans. This is the area covered by the BB&N department, which concerns itself with those communication problems that arise from noisy, complex, or confusing job situations, and those that are brought about by the relationship of men to machines.

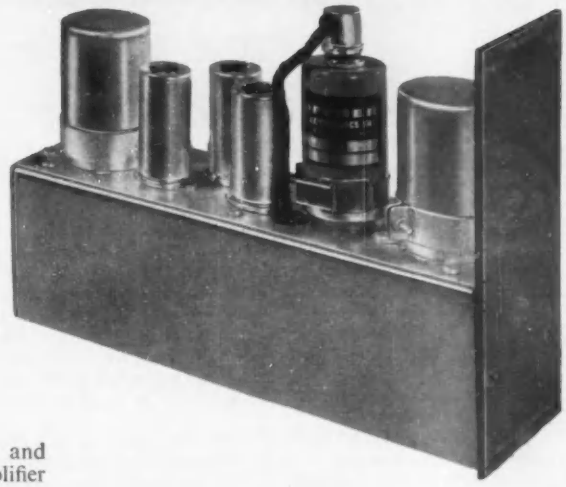
▶ **Bernard G. E. Stiff** has been named manager of United Shoe Machinery Corp.'s Atomic Power Dept., the unit that is developing, building, and testing reactor components for the Knolls Atomic Power Laboratory under a $3-million GE contract (CtE, May '56, p. 40). Under Stiff, whose department is in United Shoe's Research Div., are about 130 scientists, technicians, and production personnel. Before coming to United Shoe, he was chief mechanical engineer for High Voltage Engineering Corp. of Burlington, Vt.

▶ Chief engineer of Perkin Engineering Corp.'s new Heavy Duty Rectifier Div. is **Richard A. Rall,** most recently with Hughes Aircraft Co. in the Ground Systems Div. and before that chief engineer of Inet, Inc. He has also been with Summers Gyroscope and Collins Radio. The new division will concentrate on selenium, germanium, and silicon units for industrial applications.

▶ **Norman Perlmutter,** raised from chief engineer to vice-president of Systron Corp., will direct his company's technical development activities, primarily in the fields of data processing and automatic control systems. His previous affiliations include Beckman Instruments' Systems Dept. (chief engineer and assistant general

THE OFFNER TYPE 190

differential DATA AMPLIFIER



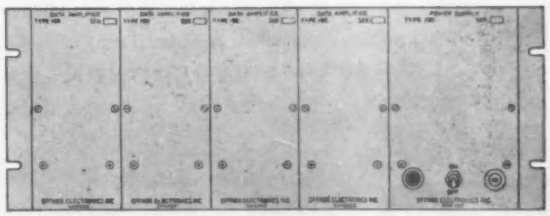
· d-c Amplifier with zero drift and 1/100th percent gain stability

For amplification of thermocouple, strain gage, and similar low level signals the Type 190 Data Amplifier provides a combination of features available in no other amplifier:

- ☆ **Infinite rejection of common-mode d-c signals**
- ☆ **One microvolt input resolution**
- ☆ **Gain stability of 0.01%**
- ☆ **Rapid step input response**
- ☆ **Linearity of 0.05%**

The true differential response of the Type 190 provides increased accuracy and simplified installation for data reduction, control, and similar applications. With infinite rejection of common d-c signals, and a rejection ratio at 60 cps of the order of a half million, errors due to ground currents are completely eliminated, and pickup problems greatly diminished.

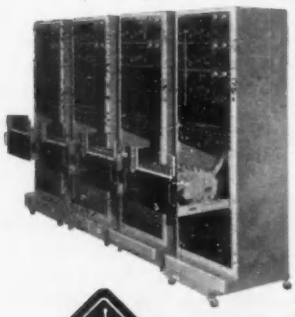
The Type 190 is designed for fixed-gain operation from low impedance sources, into high impedance load. Gain may be set at values ranging from 160 to 1200. Amplifier characteristics are unchanged at ambients from −67°F to +170°F.



Four Type 190 Amplifiers mounted in BM190 modular rack unit with Type 390 power supply.

Price of Type 190 Amplifier.....$325
Type 390 Power Supply, for up to four Type 190 Amplifiers.....$250
Type BM190 Rack Unit for four Type 190 Amplifiers and Type 390 Power Supply.....$140

Ask for bulletin No. 572 giving full technical information



OFFNER DYNOGRAPH Direct-Writing Oscillograph

Zero-drift d-c recorder with microvolt sensitivity. One amplifier type covers all requirements.

Models for one to 19 channels.

Rectilinear or curvilinear recording.

ON DISPLAY BOOTH 212 I.S.A. SHOW

Ask for bulletin No. L-861

OFFNER ELECTRONICS INC.

5320 N. Kedzie Avenue, Chicago 25, U.S.A.

Where the temperature hits 200°C . . . or drops to −65° . . . where a dry circuit is downright arid . . . or a power circuit employs 10 amperes (or even 20 amps for a short life need) . . . your best bet for reliability is a "Diamond H" Series R miniature, hermetically sealed, aircraft type relay. Their shock and vibration resistance you may take for granted.

Variations on the basic 4 PDT Series R relay perform outstandingly over such a broad area that they are frequently used to do many different types of jobs in a given application, with resultant savings in spare part inventories. The range of possible characteristics covers:

Various brackets of vibration resistance from 10 to 2,000 cps, coil resistances from 1 to 50,000 ohms, operational shock resistances of 30, 40, or over 50 "G"; mechanical shock resistance to 1,000 "G", contact capacities from 350 V., D.C., 400 MA, to 10 A., at 30 V., D.C., as well as signal circuits.

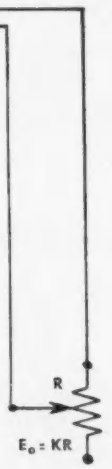
For complete information send for a copy of Bulletin R-250.

THE HART MANUFACTURING COMPANY
165 Bartholomew Avenue, Hartford, Conn.

HOW TO PROGRAM

any ramp or step function

MODEL 212A . . . 0 to 100 V dc, 100 ma. Regulation 0.1% or 0.02 volt over entire range of load and input voltage. Weight 14 lbs. 3½" H x 19" W x 9¼" D. Price $129.00 unmetered. Other models up to 3 amps.



®REGATRON (super-regulated) Power Packs have an exclusive programming feature that offers unlimited possibilities for your programming requirements. Here's how it works. Inserting a resistance across the programing input changes the REGATRON's d-c output voltage in the ratio of $\frac{R}{1000}$ . . . i.e., the output voltage always equals $\frac{1}{1000}$ of the resistance value. Use a variable resistor or potentiometer for ramp functions; switch in fixed resistors for step functions and set points. Local or remote operation.

And of equal importance, REGATRONS always deliver full current over their entire voltage range — even down to a fraction of a volt . . . with the super-regulation and stability that only a REGATRON can give.

® Registered U.S. Patent Office. Patents Pending.

Electronic Measurements Company Incorporated
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WHAT'S NEW

manager), Berkeley Scientific Co. (in charge of the Special Products Dept.), and RCA, Westinghouse Electric Corp., and The Martin Co.

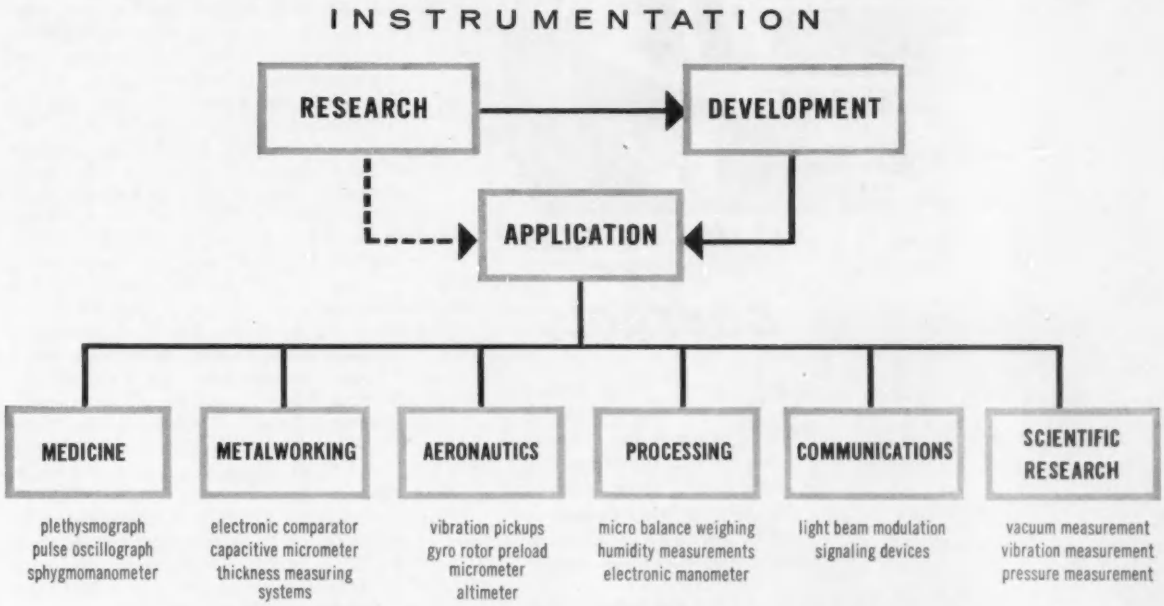
▶ Two assistant chief engineers have been appointed by Texas Instruments, Inc.: **L. D. Strom,** who has been on leave of absence earning his PhD in EE from the University of Texas, and **W. R. Hedeman Jr.,** formerly chief of electronics design at Chance Vought Aircraft and chief engineer of R&D at Bendix Radio. Both men will work on military electronics in the company's Apparatus Div.

▶ **John L. McLucas** is the new president of Haller, Raymond & Brown, Inc., succeeding **Robert V. Higdon,** who becomes vice-president for long-range planning for Topp Industries, Inc., the parent company. McLucas came to HRB from the AF Cambridge Research Center in 1948 and was appointed vice-president in 1950 and vice-president and technical director of Topp in 1956.

▶ **Edward R. Gamson** has left North American Aviation, where he was reliability coordinator for the Autonetics Div., to become director of manufacturing for Telemeter Magnetics, Inc., Los Angeles computer-memory producer.

▶ Stanford Research Institute has appointed **Kenneth R. Eldredge** director of its Engineering Research Div. and **Manning Hermes** manager of the Control Systems Laboratory, succeeding Eldredge. Eldredge, who established the laboratory, is known for his work in paper-handling techniques, printed circuitry, and electronic control systems. He supervised special electronic instrumentation development for Standard Oil Co. and worked in the U. S. Office of Naval Research before joining SRI in 1953. Hermes, head of the Basic Sciences Group since 1956, was a long-time member of the Santa Clara faculty and later with IBM.

▶ Westinghouse Electric Corp. has transferred **W. H. Brandt** from its Director Systems Dept., where he was engineering manager, to the Sunnyvale (Calif.) Mfg. Div. as director of advanced systems engineering. **L. W. Golden,** overall manager of DSD, also moves out, to become manager of the General-Purpose Control Dept. at Buffalo, N. Y. His successor is **R. W. Lang,** formerly manager of manufacturing for DSD. In his new post, Brandt will direct work on special studies related to the development of handling and launching systems for the Polaris missile. He joined West-



an idea is the solution to every problem

Decker Aviation is a company of ideas.

Not long ago, for example, Decker took the idea of an ionization transducer and brought the idea to reality . . . then used it imaginatively to solve pressing problems in any number of far flung fields.

In medicine, Decker applied the transducer to the improvement of such basic instruments as the plethysmograph . . . giving medical researchers a new magnitude of sensitivity in their explorations.

For geophysical research, Decker ideas made possible instrumentation that, mounted in the nose of an Aerobee-Hi rocket reaching an altitude of 125 miles, continuously and accurately measured both ram and ambient atmospheric pressures at speeds in excess of a mile per second.

Applying new ideas to the micrometer comparator, Decker gave the production line an instrument for measuring an object without physical contact to within a few millionths of an inch.

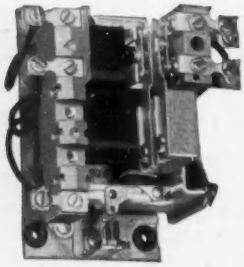
All the examples listed on this page hardly begin to show the extent of Decker accomplishments. For one problem after another, we have found the idea . . . developed it into a solution . . . built prototypes . . . even manufactured finished instruments.

We would honor an opportunity to evaluate your problems. Our ideas may very well be their solution.

DECKER AVIATION CORPORATION

Philadelphia, 25

LIQUID LEVEL B W and INDUSTRIAL CONTROLS



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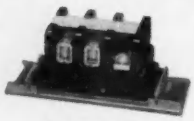
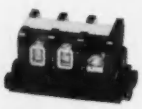
2212 E. Maple Road, Birmingham, Mich.

FIRST IN THE FLOATLESS CONTROL FIELD

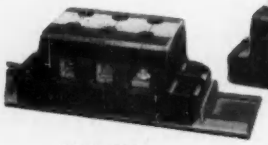
BUCHANAN ...for your terminal block Requirements



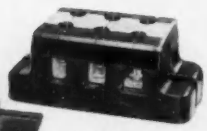
MEDIUM DUTY pres-SURE-blocks (Channel Mounting)



MEDIUM DUTY pres-SURE-blocks (Direct Mounting)



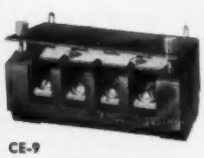
HEAVY DUTY pres-SURE-blocks (Channel Mounting)



HEAVY DUTY pres-SURE-blocks (Direct Mounting)

SECTIONAL pres-SURE-blocks (for #22 thru #4 wire-750 volts)
Medium Duty:
#22-#8, contacts on 7/16" centers.
Heavy Duty:
#18-#4, contacts on 5/8" centers.
Any number of circuits — assembled without fastening hardware.
Complete blocks or separate sections.
Direct or channel mounted.
Integral or separable marking strips.
Contacts for stripped or terminal-ended wires.

"ONE PIECE" TERMINAL BLOCKS (for #16 thru #6 wire-750 volts)
Contacts on 5/8" centers.
4, 6, 8, or 12 circuits.
Screw, thumb screw or hinged covers.
Contacts for stripped or terminal-ended wires.
Jumper bars available.



"ONE PIECE" Terminal Blocks

Send for Bulletin CE-9

IN CANADA — GASACCUMULATOR CO., (CANADA) LTD. 12 Gower St., Toronto 16, Ont.
EXPORT — PHILIPS EXPORT CO., INC. 100 E. 42nd St., New York, N.Y.

BUCHANAN ELECTRICAL PRODUCTS CORPORATION HILLSIDE, NEW JERSEY

WHAT'S NEW

inghouse in 1936 and has held managerial jobs in research, materials engineering, feeder engineering, and new-products engineering.

▶ **H. W. Cory** is the new assistant manager of Allis-Chalmers Mfg. Co.'s Control Dept., and **W. F. Eagan** is the new man in charge of control engineering. Cory joined the company in 1941 and has been chief engineer in the department since 1955. Eagan, supervisor of regulator engineering and circuit development since the same year, came to A-C in 1947.

▶ **Paul E. Twohig** has been named manager and **Abraham A. Perez** senior systems engineer in the Product Development Dept. of National Cash Register Co.'s Electronics Div. Twohig comes from the Dayton Branch of PDD. Perez, most recently a senior systems engineer at Datamatic Corp., has also been with Hycon Eastern, Inc., RCA Victor, Alden Products Co., Manila Observatory, and the University of Manila, where he taught physics.

▶ Eastern Air Devices has appointed **Edmond J. Burke,** formerly section head in the Engineering Dept., assistant chief engineer. He was with Brewster Aircraft Co. before joining Eastern in 1946.

▶ New control-field representatives on the Committee on Commercial Uses of Atomic Energy of the U. S. Chamber of Commerce include: **Gordon Dean,** senior vice-president, General Dynamics Corp.; **George Havas,** vice-president and general manager, Kaiser Engineers; **Raymond F. Jahn,** president, Ford Instrument Co.; **Michael Michaelis,** coordinator of nuclear energy stuides, Arthur D. Little, Inc.

▶ The new director of research for Mycalex Corp. and its associated companies is **Arthur J. Warner,** who most recently was chief engineer of the Rectifier Div. of Standard Telephones & Cables, a division of IT&T, in his native Great Britain. He will have responsibility for the materials and product phase of a new Mycalex program in electronic components and glass-bonded mica, cermoplastic insulation, and synthetic mica. He was with various IT&T companies from 1930 until his present appointment.

▶ New senior research engineers at National Cash Register Co. are **Norman Nisenoff,** formerly with the Signal Corps Engineering Laboratories, and **James E. Meinhard,** formerly with General Electric Co.'s Hanford atomic products operation at Richland, Wash. Nisenoff supervised work in digital

LIMBERING UP LUMBER-HANDLING WITH

CYPAK

by putting memory into the carriage conveyor system at Lutcher & Moore's Orange, Texas Mill

CYPAK* static controls—outliving conventional relays 15 times over—are now being used at Lutcher & Moore's Orange, Texas Mill to control resaw conveyors on the lumber industry's first aluminum log carriage.

By putting memory into the carriage conveyor system, CYPAK automatically and unerringly separates waste from good boards, diverts slabs to the chipper, automatically sorts and grades, and returns boards requiring another cut back to the saw. Result: a faster, more efficient operation . . . substantial savings in materials handling . . . greater utilization of raw materials.

For complete information about the ways CYPAK can benefit you, call your Westinghouse sales engineer. Or, write Westinghouse Electric Corporation, Box 868, Pittsburgh 30, Pennsylvania. J-22063

YOU CAN BE SURE...IF IT'S

Westinghouse

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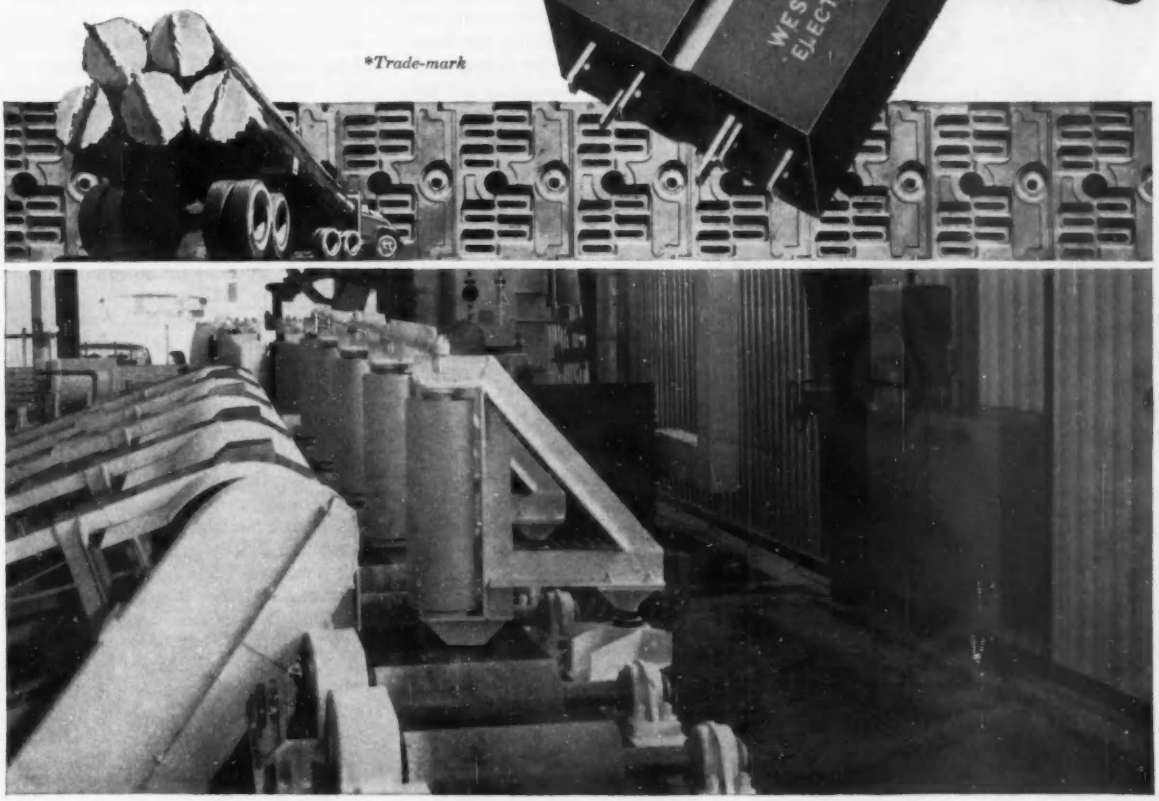


RdF STRAPON

RESISTANCE THERMOMETER

INTRODUCING STRAPON . . . NEWEST ADDITION TO THE RdF FAMILY OF SURFACE TEMPERATURE MEASURING DEVICES

STRAPONS, developed by Arthur C. Ruge Associates Inc., answer the need for a moisture resistant, portable, reusable and truly flexible surface temperature transducer.

Usable from — 100°F to 500°F, the STRAPON consists of a STIKON-type element (similar to the SN-1) intimately bonded to a thin (.002") stainless steel backing with an overmold of **SILASTIC** permitting usage in the presence of • radioactive fields • high humidity • water • alcohols • salts • mineral and vegetable oils • certain acids and caustics, etc.

STRAPON flexible leads — supplied in any length — are molded in place and insulated with silicone rubber. STRAPONS are also available mounted on a backing plate for ambient or for surface measurement.

ACTUAL SIZE

STRAPON CLAMP — one of many adapters available

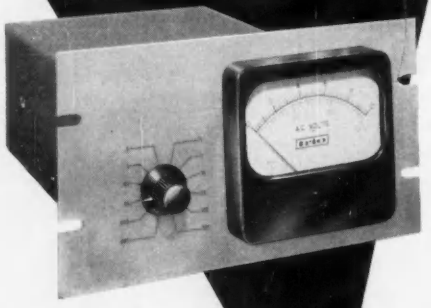
In addition to RdF STRAPONS and standard STIKONS, we manufacture a wide variety of special elements and systems for temperature measurement and control. Send for free literature or write stating your special problem.

ARTHUR C. RUGE ASSOCIATES INC.

733 CONCORD AVENUE, CAMBRIDGE 38, MASSACHUSETTS

new... **trio**

low-level BUILD-IN AC VTVM *with* BUILT-IN ISOLATION



Designed especially for **panel-mounting**, new model 109-1 reads down to 20 microvolts on its 1 MV range with 2% full-scale accuracy, 10 megs input impedance, response 20-80,000 cps . . . features signal & power circuits and mounting panel **all isolated** from each other . . . extreme stability — wide line variations do not affect accuracy . . . calibration of gain and frequency response without removal from panel . . . feedback and printed circuitry for exceptional reliability and simple maintenance . . . size 5¼" h x 9½" w x 9¾" d — panel fits standard modular-type consoles. Price $199.50

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when ordinary instruments are too big or inadequate . . .

trio

. . . the leader in panel-mounting electronic instruments

WHAT'S NEW

computer techniques at SCEL; Meinhard was a research chemist and problem leader in charge of fundamental and applied research programs.

► **Richard T. Denton,** who is working for a doctorate in engineering at the University of Michigan, is the winner of the first National Electronics Conference fellowship in electronics. The $2,500 award is supported by eight universities (Illinois Tech, Northwestern, University of Illinois, Michigan, Michigan State, Purdue, Notre Dame, and Wisconsin), and four societies (AIEE, IRE, Radio-Electronics Television Mfrs. Association, and Society of Motion Picture & Television Engineers). It's good for a year at any one of the schools listed.

► **Robert L. Burr,** recently with Northrop Aircraft, Inc., has joined Mycalex Electronics Corp. as a telemetry specialist. He has had additional instrumentation and telemetry experience with Bell Aircraft Corp. and Spaulding Fiber Corp.

► The Systems Div., Daystrom, Inc., appointed **Manny Otis,** formerly with the AF Cambridge Research Center's Computer Laboratory, as a systems engineer. At the Cambridge Center he worked on magnetic-core memories for a radar data-processing digital device; at Daystrom he'll specialize in the logical design of systems using magnetic and transistor components, and in the development of digital circuits.

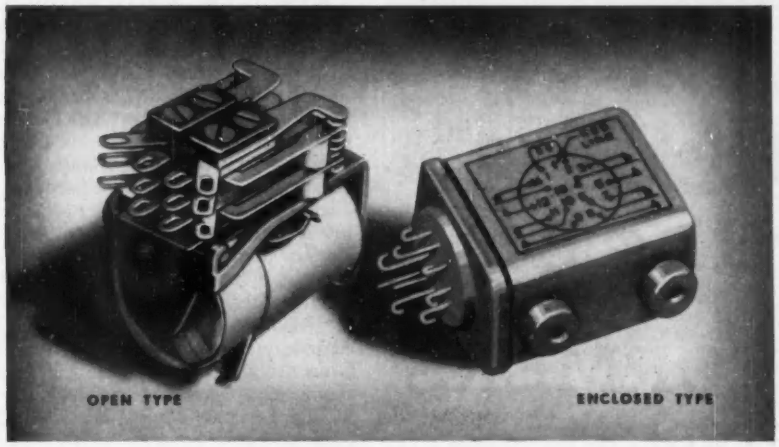
► New manager of the Product Engineering Section in ElectroData's Small Systems Div. is **John E. Ranks,** formerly project manager for missile devices at Hycon Mfg. Co.

► **Richard Ochs,** formerly vice-president for American Measuring Instruments Corp., has joined Philips Electronics, Inc., as production manager of the Instruments Div. His duties will involve x-ray diffractometers, spectographs, diffraction units, and Autrometers.

► **Frederick A. Mitchell** has been named assistant chief engineer for Stromberg-Carlson's Electronics Div. He joined the company in 1942 and has been a section head in the division since 1956.

► Two new GE managers are **M. R. Johnson,** who heads up the new Armament & Control Section of the Light Military Electronic Equipment Dept., and **Hugh R. Lowry,** who takes over application engineering in the Semiconductor Products Dept. Johnson, formerly manager of engineering in the LMEE Dept. and a holder of several citations for his work in trans-

R-B-M Miniature Multipole Relays of Proven Reliability



Light weight, Small Size Open and Hermetically Sealed Types for Electronic and Communication Application

APPLICATION: R-B-M Miniature Multipole Relays are used where the prime factors in switching electronic circuits are small size, light weight and reliability. These proven designs are produced for switching low power circuits, low capacitance circuits and power circuits. 125° C insulation now available on some versions. Coils can also be designed for plate circuit.

CONSTRUCTION:

Magnet Frame—Four sizes available on open type relays and three sizes on hermetically sealed type.

Contacts—Cross-bar palladium welded to nickel silver springs or button contacts on Beryllium copper springs.

Terminals and Mountings—Glass headers provided with either solder or plug-in type terminals with many various types of mountings available. Octal type plug-in headers can be provided on the HL enclosure. Plug-in terminals to fit either 9 or 14 pin standard sockets. Maximum of 14 pins for solder connections.

TYPICAL SPECIFICATIONS*

Open	Maximum Coil Resistance (OHMS)	Minimum Power Requirements Per pole at 25°C (WATTS)	Maximum Contact Form With rated current at 32 V.D.C. or 115 V.A.C. (non-inductive load)	Maximum Coil Watts	Enclosed
SM	9,000	.2	4 PDT 5 Amps. or 3 Amps. 6 PST 3 Amps.	3.75	HSM
SMD-2	9,000	1.0	SPNO Parallel Contacts Make 80 Amps. Break 20 Amps. at 32 V.D.C.	3.75	HSMD-2
SC	18,500	.16	4 PDT 5 Amps. or 3 Amps. 6 PST 3 Amps.	4.5	HPSC
SA	18,500	.14	4 PDT 5 Amps. or 3 Amps. 6 PST 3 Amps.	4.5	HLSA
SM-RF	9,000	.2	SPNO, SPDT, DPNC, SPNC, DPNO	3.75	HSM-RF HLSM-RF
SAD-2	18,500	1.0	SPNO Parallel Contacts. Make 80 Amps. Break 20 Amps. at 32 V.D.C.	4.5	HLSAD-2

*Other ratings and specifications available.

For additional information write for Bulletin No. 1050

RBM DIVISION

Manufacturers of Magnetic Controls and Devices / LOGANSPORT, INDIANA

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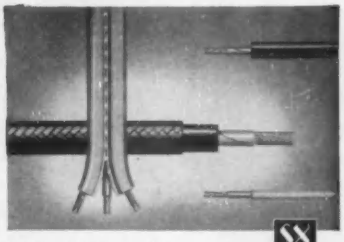
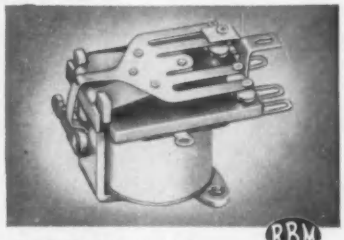
other outstanding
***ESSEX ENGINEERED**
production proven products



WIRE AND CABLE

A full "Extra Test" line of lead, test lead, appliance, automotive and refrigeration wires, plus submersible pump cable and 200° C. Sil-X insulations are examples of the versatility of "Essex Engineering".

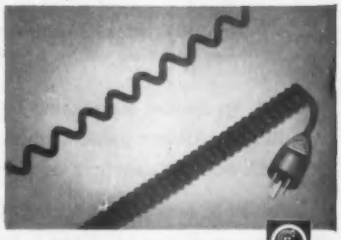
Wire and Cable Division
Fort Wayne, Indiana



MINIATURE RELAYS

The Type MS Miniature Sensitive Relay is ideal for any application requiring a compact, highly reliable single pole D. C. device, where a low cost solution is required because of volume usage and competitive problems. Request Bulletin No. MS-1.

R-B-M "Control" Division
Logansport, Indiana



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The "spring" in Coiled Cords automatically synchronizes with moving components that are electrically powered. There are no looping, tangling cords in the way . . . because Coiled Cords extend and retract as needed. Write for new literature.

Cords Limited Division
DeKalb Illinois

ESSEX WIRE CORPORATION

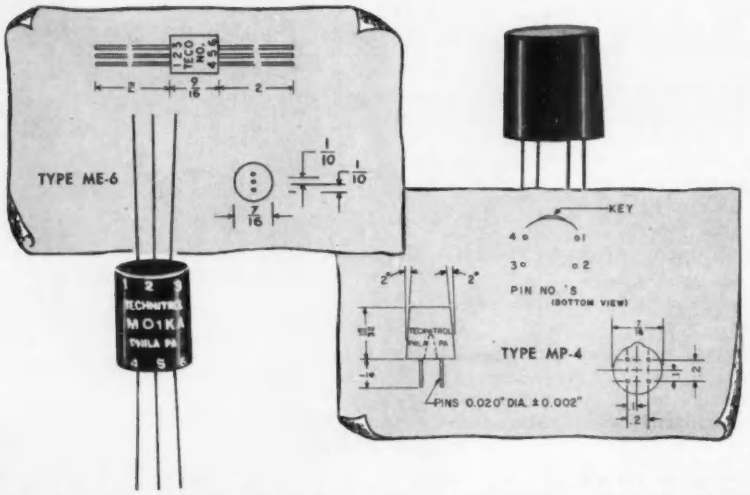
miniature

encapsulated

PULSE

TRANSFORMERS

by TECHNITROL



Wound on ferrite cores, the Type M series is available in a variety of windings to cover pulse widths from 2 microseconds down to .05 microsecond, wound inverting or non-inverting.

While the M series is particularly adapted to subminiature and transistor circuits, we design and build pulse transformers to fit specific circuits or to meet definite mechanical or thermal requirements, including MIL-T-27A.

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mitters, will have headquarters at Johnson City, N. Y. He joined the company in 1932.

▶The W. L. Maxson Corp. has named **Irving Leeds** manager of transformer engineering in its Maxson Instruments Div., and **Gordon A. Carlson** vice-president at Old Forge, Pa. Leeds has been assistant chief engineer at American Bosch Arma Corp. and chief engineer at Ferranti Electric, Inc., Carlson vice-president, director, and general manager of Kearfott Mfg. Corp.

▶**Joachim W. Muehlner,** a German scientist who was brought to this country after World War II to direct the high-frequency and telemetering laboratory in the R&D Div. of Army Ordnance at Fort Bliss, Tex., has been appointed a consultant in Lockheed's Missile Systems Div. at Palo Alto, Calif. A former associate of **Wernher von Braun,** Muehlner left Fort Bliss in 1950 to become technical director of the Range Instrumentation Development Div. of Army Ordnance at White Sands Proving Grounds, N. M., and later joined the instrumentation Section of Holloman AFB.

McKay Professor Gets Key Harvard Engineering Post

Harvey Brooks, who has been Gordon McKay professor of applied physics at Harvard University since 1950, has been appointed dean of engineering and applied physics there, succeeding John H. Van Vleck, Hollis professor of mathematics and natural philosophy. The changes will take place in September, when Van Vleck, who has headed the E&AP Div. since 1951, begins a sabbatical to Europe and the Orient.

Brooks, now in England doing research as a Guggenheim fellow at The Cavendish Laboratory, Cambridge, has had experience in industrial and governmental research as a research associate of the Underwater Sound Laboratory at Harvard during the war, as professor of engineering research and assistant director of the Ordnance Research Laboratory at Pennsylvania State University, and as a research associate and associate laboratory head of the Knolls Atomic Power Laboratory, where he worked on GE's first nuclear reactor. He is a fellow of the American Physical Society, the Acoustical Society of America, and the American Academy of Arts & Sciences.

Van Vleck, whose Hollis professorship is the oldest endowed chair of

science in North America, came to Harvard in 1935 from the universities of Minnesota and Wisconsin, where he taught physics. During the war he steered Harvard's Theory Group in the Radio Research Lab and acted as a consultant to the Radiation Lab.

Trumpler Heads ME School at University of Pennsylvania

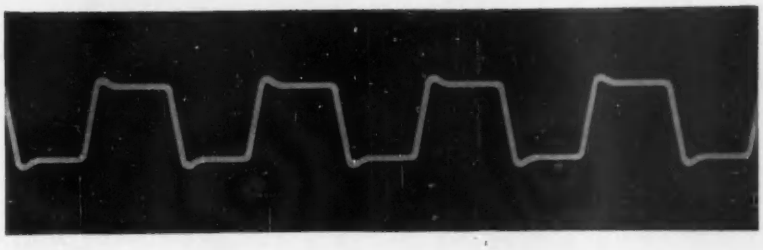
In another important change in academic circles, Paul R. Trumpler, professor of mechanical engineering in charge of machine design at Illinois Tech, becomes director of the School of Mechanical Engineering at the University of Pennsylvania and professor of mechanical engineering there. Lee N. Gulick will relinquish his duties as head of the U. of P. school in September, but will continue as professor of mechanical engineering and senior research engineer in the university's Institute of Cooperative Research.

Trumpler left Illinois Tech in 1941, where he had been instructing in heat-power engineering, to go into industry, first as a development engineer with Western Electric, then with the M. W. Kellogg Co., and finally with Clark Bros. Co. He returned to the university as a professor in 1949.

Four Young PhD's Earn Harvard Professorships

The word is that control engineering is a young field, and Harvard University's recent appointments of four assistant professors on the Gordon McKay Endowment proves it. Youngest of the four, all of whom hold PhD's, is Harvey Greenspan, 24, an applied mathematician whose belt is already notched with work done for aviation research centers of the Navy, the Air Force, Cornell University, North American Aviation Co., and Avco. Next, going up age-wise, is Peter Calingaert, 25, who has been on the staff of the Harvard Computation Laboratory since 1955.

Then comes Richard V. Jones, 27, a former senior engineer in the Shockley Semiconductor Laboratory of Beckman Instruments, Inc. He worked there on transistor design and semiconductor crystal technology. He has also done research in paramagnetic resonance and diamagnetic resonance in gas plamas. Finally, there is Anthony Oettinger, 28, a linguist and applied mathematician who has been doing pioneer research in the Computation Laboratory on machine translation of scientific Russian. He has also served as a consultant to Arthur D. Little, Inc., the Air Force, and IBM.



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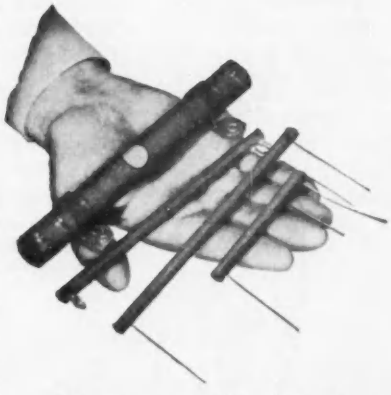

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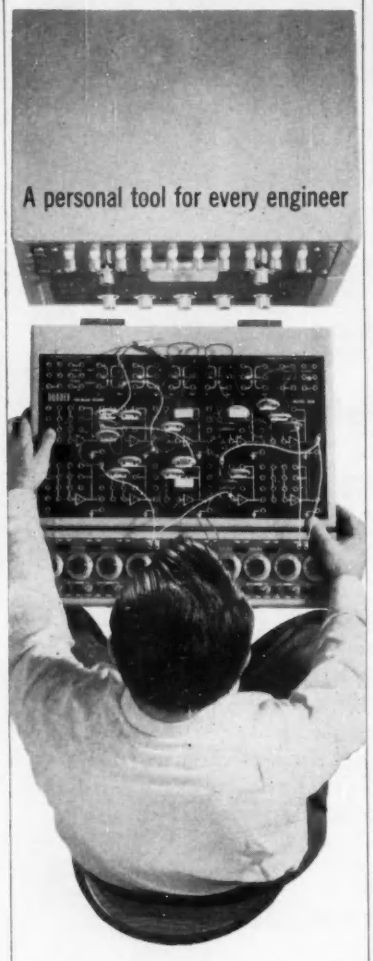

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ABSTRACTS

Reactor Control

From Part IV, Sections D, E, and F of "Experimental Boiling Water Reactor", prepared for the U.S. Atomic Energy Commission by Argonne National Laboratory, University of Chicago. Publication No. ANL 5607, 232 pp. U.S. Government Printing Office, 1957.

The instrumentation of the new experimental boiling water reactor at Argonne National Laboratory may be divided into three categories: nuclear, radiation monitoring, and plant.

The instruments used to measure the neutron density of the reactor have a wide variety of power, flux, and current ranges. Two fission counter chains, used during reactor startup to read multiplication of neutrons at source level, accommodate either BF_3 or fission pulse chambers as sensing elements. The electrometer, a sensitive current-measuring instrument with a vibrating capacitance modulator, measures the output current of a compensated ionization current chamber. It has a minimum sensitivity of 3×10^{-6} amp full-scale and a maximum sensitivity of 3×10^{-13} amp full-scale.

In addition, there is the micromicroammeter, a modulated chopper-type dc amplifier with a variable input resistor. Its output is displayed on a meter at the reactor console and is connected to a linear recorder through a selector switch. The linear flux recorder displays both the output of the electrometer at low power levels and the micromicroammeter output from intermediate to full power level. A galvanometer chain, a log-period chain with log-flux recorder, and three safety trip chains that shut down the reactor under high flux conditions complete the nuclear instrumentation.

The radiation monitoring system has been designed to:

- register any changes in radiation levels which may indicate abnormal operating conditions or contamination from fission products
- indicate general conditions of personnel safety
- initiate reactor shutdown and closure of building air inlet and exhaust systems when there is an excessive amount of radiation present in the building exhaust air

The overall system consists of 14 gamma monitor channels and one special channel for detecting fission products in the condenser exhaust air. The detector for each gamma channel is a gamma-sensitive ionization chamber connected to an amplifier by a few feet of coaxial cable. All gamma amplifier circuits are of the dc feedback type with range switching over four decades.

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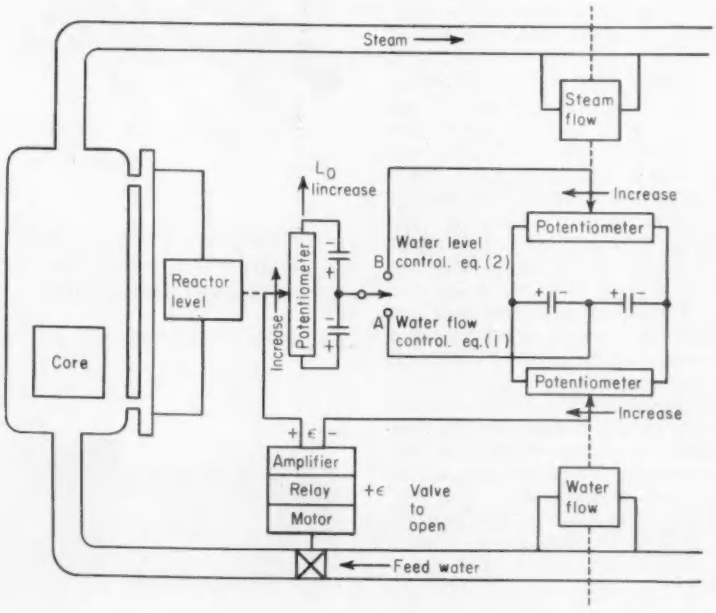

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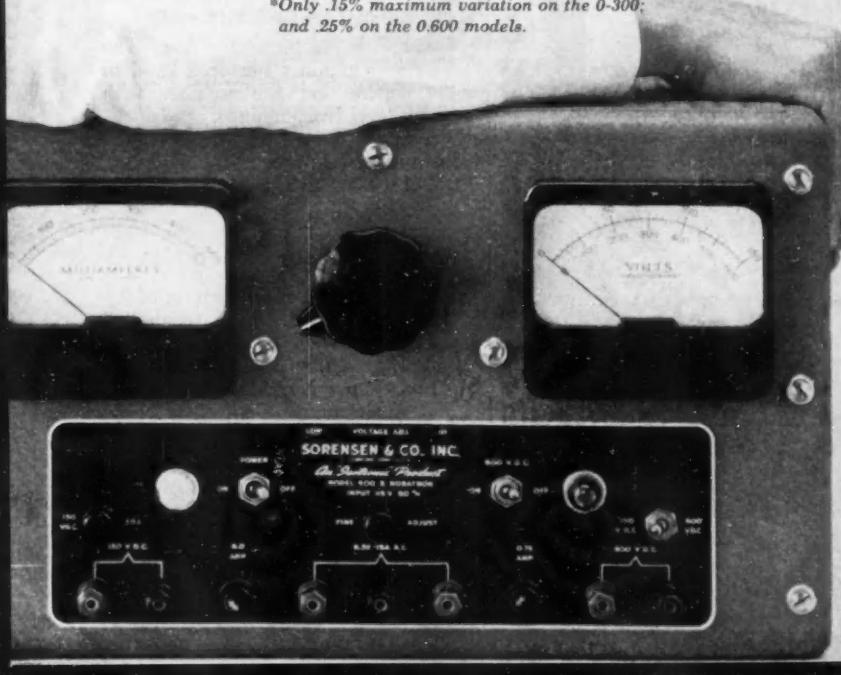

SPECIFICATIONS

Model	300B*	325B	500B	600B	1000B
Output Voltage VDC	0-300	0-325	0-500	0-600	200-1000
Output Current Ma	0-150	0-125	0-300	0-500	0-5000
Regulation Accuracy	±0.15%**	±0.5%	±0.5%	±0.25%	±0.5%
Ripple (MV-RMS)	5 max.	5 max.	5 max.	3 max.	20 max.
Bias Supply (VDC)	—	0-150	0-150	0-150	—
Max. Bias Circ. Imp. (Ohms)	—	25000	25000	50000	—
Max. Int. Imp. (Ohms)	2.0	2.0	2.0	2.0	2.0
AC Voltage (CT Unreg.)	—	6.3/10 amps	6.3/10 amps	6.3/15 amps	—
Filament Voltages (Unreg.)	6.3 at 5 amps, series or parallel (two outputs)	—	—	—	—

**may be connected positive or negative, in series or parallel*
***or ±0.3 volts, whichever is greater*

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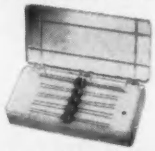

Engineering kits containing various assortments of subminiature and miniature pulse transformers are available. Kit KA4, pictured above, contains five different hermetically-sealed subminiature pulse transformers conforming to MIL-T-27A specifications.

Blocking Oscillator Bulletin BO.
Pulse Transformer Bulletin KA.

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ABSTRACTS

vides a direct indication of reactor water level from a sight glass, and main-line steam pressure from a bourdon gage. The following remote controls are provided at the viewer: electrical focus, target voltage, and beam voltage adjustments; pan and tilt motions of the camera; and mechanical lens focus.

All temperatures are measured with iron-constantan thermocouples or resistance thermometer detectors. Multipoint temperature recorders have reference junctions located inside the plant shell. Pressure transducers are of the force-balance type, the pressure-sensitive elements depending on the ranges involved. Differential pressures are measured with Barton cells, level with a differential pressure cell coupled to a beam balance unit.

Water and steam flow are measured with flow nozzles, while air flow is measured by using the beam balance unit to determine the position of a plug inside a tapered flow tube. Except for the control-rod drives, all position indication is done with potentiometers attached to the valve stem or other device being measured.

One of the control systems, the feed-water control system, is shown here. Either flow or level can be controlled. Note the switch near the center of the drawing. With this switch in position *A* (proportional level control) this represents system error:

$$e = K_1(L_o - L) - K_2W$$

where L_o is reference level, L reactor level, W feed-water flow, and K_1 and K_2 are constants.

In position *B*, three-element control is used:

$$e = K_1(L_o - L) + K_2(S - W)$$

where S is reactor steam flow. The error e determines the dead band of the system and the accuracy with which level is maintained.

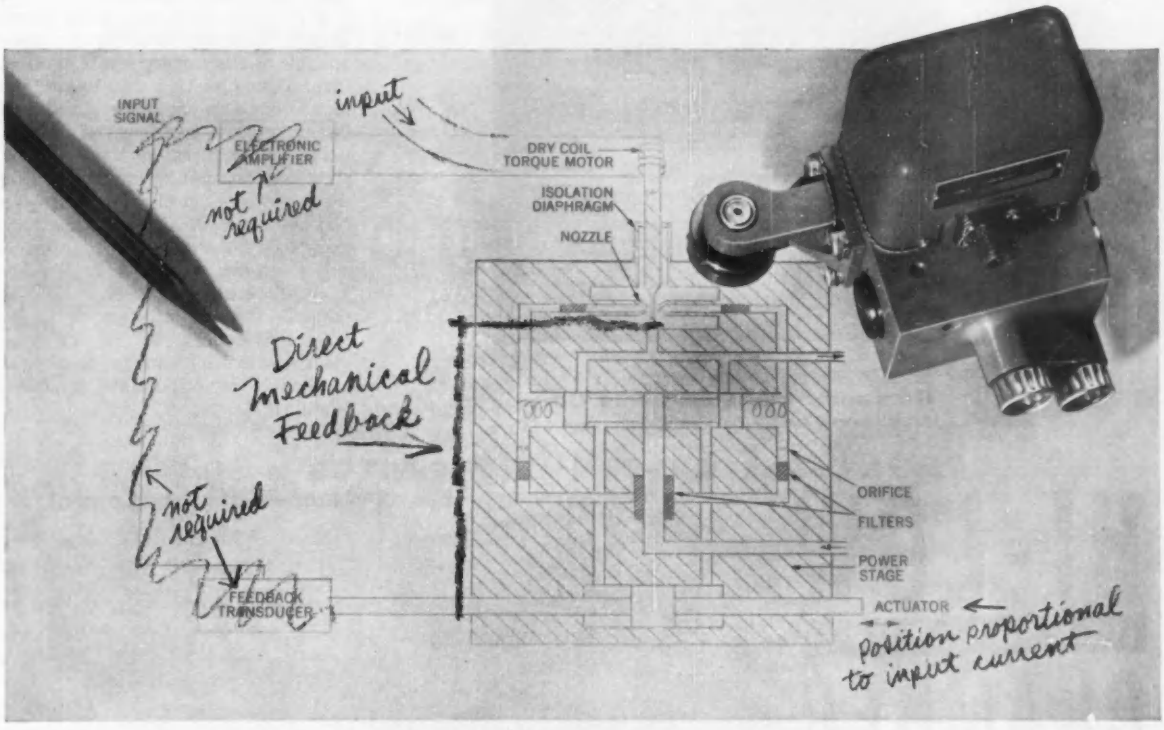
The control room contains all the instrumentation necessary for the control of the reactor and the power plant.

Power System Economics

From "Economic Evaluation of Industrial Power System Reliability" by W. H. Dickinson, Esso Research & Engineering Co. AIEE Transactions Paper No. 57-639, presented at the Summer General Meeting, Montreal, Quebec, Can., June 24-28, 1957.

Soon after starting the design of an industrial plant, the electrical engineer

EXACT POSITIONING WITH MECHANICAL FEEDBACK IN NEW HIGH PERFORMANCE SERVO SYSTEM



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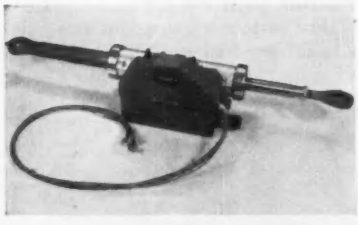

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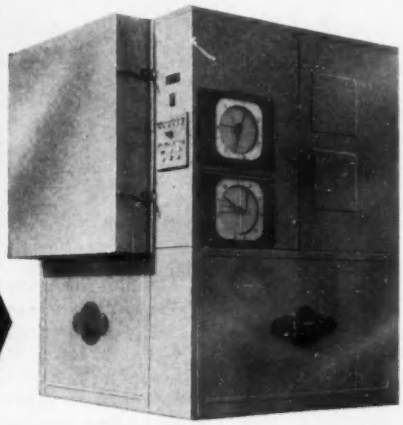

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ABSTRACTS

must determine the type of power system required. This paper describes methods for analyzing the relative reliability of different types of industrial power systems, and demonstrates how the reliability improvements may be evaluated on an economic basis. Armed with this information, the engineer can determine the amount of incremental investment justified.

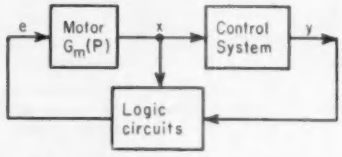
The paper covers four main points. First, a technique for the economic analysis of alternatives involving incremental investments is developed. This technique is a simplification of the discounted-cash-flow method of comparing alternatives. Secondly, probability and its application to power system reliability problems is discussed. Next, these probability principles are applied to several typical industrial power systems. Figures are presented to illustrate each of the systems considered. Finally, a complete typical example is worked out. In this example, the actual incremental investment justified to increase system reliability is evaluated.

Near—Optimum Control

From "Optimizing Control Systems" by Robert L. Cosgriff and Ronald L. Emerling, Ohio State University. AIEE Paper No. CP 57-778, presented at the AIEE Summer General Meeting, Montreal, Quebec, Can., June 24-28, 1957.

An optimizing control system, as defined in this paper, adjusts some variable to a minimum or maximum value. However, since this optimum adjustment usually will change with time, an optimizing system cannot be considered exactly adjusted for any extended period and must constantly readjust itself. The best that can be hoped for is near optimum value for the controlled variable at all times.

The system discussed in this paper was designed to analog the processes of a human operator, in the manual control of the same variable using logic or switching circuits.



The figure shows a simplified block diagram of the optimizing system con-

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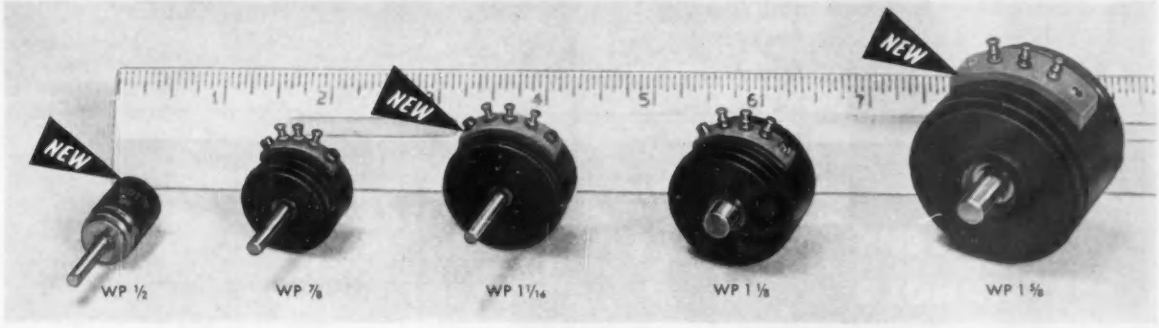

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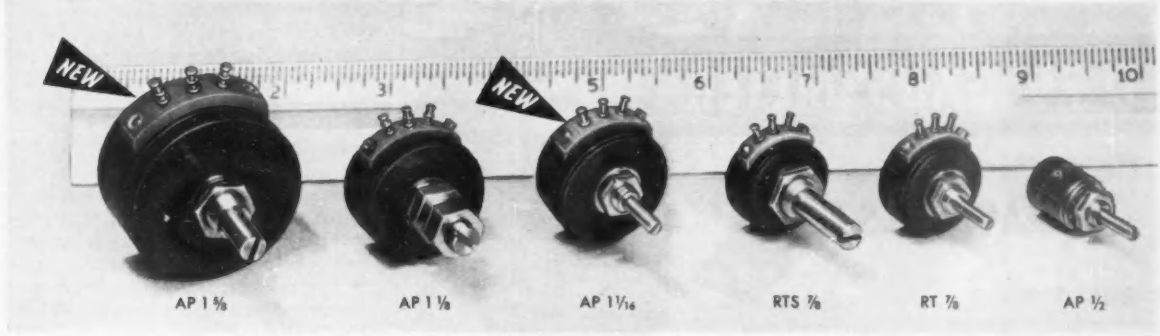

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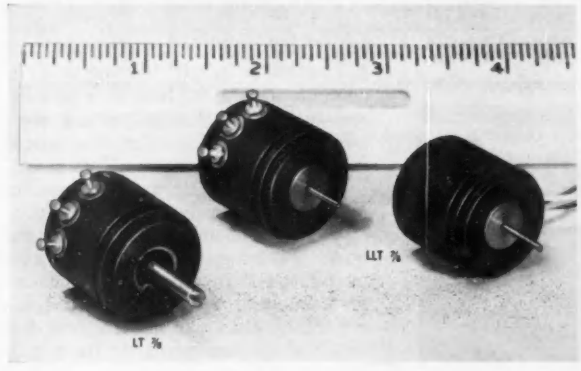

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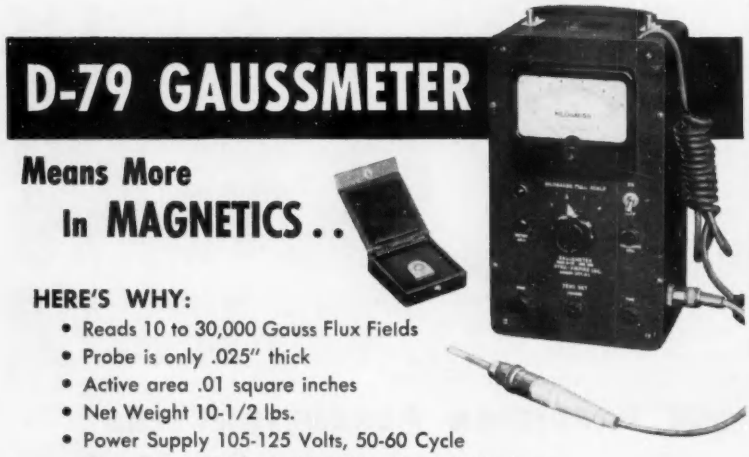
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ABSTRACTS

sidered. The motor position, which adjusts the control system, is represented by x while the optimized variable is represented by y. Logic circuits adjust motor-drive voltage, e, such that motor acceleration is always toward a position where y is a maximum or minimum.

The proposed system is analyzed by using the nonlinear gain technique. The magnitude of the steady-state oscillation of x about its optimum position is determined, and a hunting loss established. By adding two more logic circuits, two more modes of operation can be included to improve operation of the system. The first is a searching mode which will hunt for a reasonable value of dy/dx, and the other is a mode that will average maximum and minimum values of motor position x.

Navigating Techniques

From "Principles of Self-Contained Navigation" by H. H. Bailey, The Rand Corp. IAS Preprint No. 736, Paper presented at the National Summer Meeting, Los Angeles, Calif., June 17-20, 1957.

Today the field of self-contained air navigation is growing at a tremendous rate. About a billion dollars is being spent annually on this equipment, a third of which is earmarked for research and development. Most demand for self-contained navigation systems comes from the military, and thus much of the work is classified.

The physical principles involved, however, are general knowledge, and it is these principles rather than any specific design problem with which the author is concerned. Basically, navigation consists of two parts: 1) determining present position, and 2) steering a proper course. Only part 1 is considered here. There are two ways in which present position can be determined, direct observation of terrestial or celestial objects, when the process is commonly called "getting a fix"; computation on the basis of a past fix and an integration of velocity or double integration of acceleration, when it is called "dead reckoning".

Today most fixing methods involve locating the true direction of the vertical. This becomes a problem on board a moving vehicle, because any instrument that responds to the directional pull of gravity (plum bob, pendulum, etc.) will also respond, by virtue of its own inertia, to the accel-

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Fixed Phase Voltage	26v	115v	115v	26v
Control Phase Voltage	26v	115v	115v	26v
Frequency	400	400	400	400
Max. Power @ Stall	6	5	5	6
No Load Speed	10,500	10,000	10,000	10,500
Generator				
Excitation Voltage Phase 1	26v			26v
Output Phase 2	0.3v/1000 RPM 100,000 ohm load			0.3v/1000 RPM 100,000 ohm load
Null	.012v			.012v
Wobble Voltage	.007v			.007v
(Power Excitation)	3.5 watts Max.			3.5 watts Max.
Linearity	0.5% to 4000 RPM			0.5% to 4000 RPM
Potentiometer				
Mechanical Rotation	360°	360°	360°	360°
Resistance	1000 ohms	50,000 ohms	50,000 ohms	1000 ohms
Accuracy of Total Resistance	±5%	±5%	±5%	±5%
Electrical Angle	350°	350°	350°	350°
Servo Block Unit				
Ambient Temperature	−55°C to 72°C	−55°C to 72°C	−55°C to 72°C	−55°C to 72°C
Altitude	−1000 feet to 55,000 feet	−1000 feet to 55,000 feet	−1000 feet to 55,000 feet	−1000 feet to 55,000 feet
Life	3000 hours excluding pot.	3000 hours excluding pot.	3000 hours excluding pot.	3000 hours excluding pot.
Gear Train				
Ratio	1000 : 1	336 : 1	167 : 1	10,000 : 1
Dust Enclosed per	Section 4.11 MIL-E-5272A	Section 4.11 MIL-E-5272A	Section 4.11 MIL-E-5272A	Section 4.11 MIL-E-5272A
Backlash	Anti-Backlash gear on pot.	1°	1°	Anti-Backlash gear on pot.
Synchro				
Input Voltage—Stator	11.8v			
Output Voltage—Rotor	10.6v			
Clutch Brake				
Input Voltage		100v dc	100v dc	
Input Power		2.0 watts Max.	2.0 watts Max.	
Operate Time—Energize		5 milliseconds	5 milliseconds	
Operate Time—De-energize		20 milliseconds	20 milliseconds	

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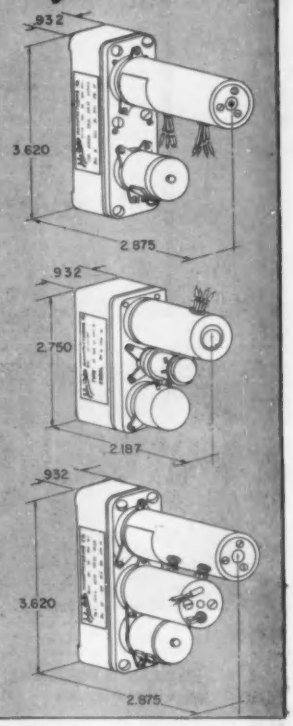

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clutch	synchro
brake	motor-tach
clutch-brake	potentiometer

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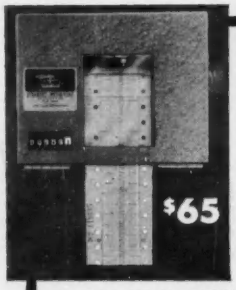

Modern plant operation demands the most efficient and accurate means of evaluating both machine and man-power production . . . that's why leading companies everywhere are equipping their production lines, processes, systems and office machines with Time Recorder-Totalizers.

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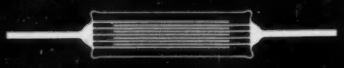

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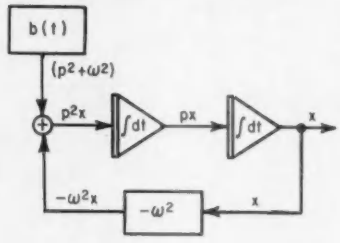
BOX 544 A. • BRIDGEPORT 1 • CONN.

ABSTRACTS

eration of the vehicle. Common accuracies are as follows: at fixed stations on the ground, verticals are good to within 1 sec of arc, or 100 ft on the earth's surface; at sea, measuring horizontals rather than verticals, fixes are accurate to within 1 min of arc or about a mile on the earth's surface; in the air, a common value is 10 miles, corresponding to $\frac{1}{6}$ deg error in the vertical.

Of all the dead-recokning techniques suitable for aircraft, the most accurate is Doppler radar, the first dead-reckoning system with no inherent limitations. Another and distinctly different kind of dead reckoning is inertial navigation, really the ultimate in self-containment though inertial systems do not approach the accuracy of Doppler radar.



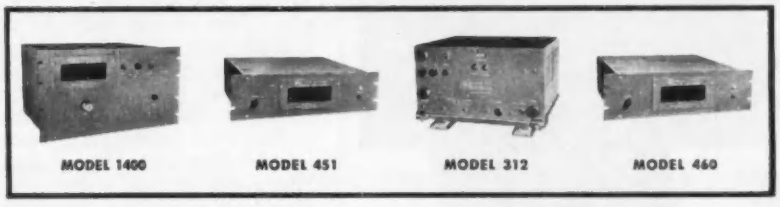
After presenting some idea of the fantastic component performance required, the author closes with a development of the basic differential equation of all inertial systems and a block diagram (shown) of a simple inertial system in one dimension.

New Control Problems

From "Use of Analysis Instrumentation in Process Control" by A. R. Aikman of Schlumberger Well Surveying Corp. Paper presented at the Third National Symposium on Instrumental Methods of Analysis of the Instrument Society of America, Chicago, Ill, June 13, 1957.

The comparatively recent introduction of analytical instruments as active components in control systems has accentuated a number of existing problems and introduced some special new ones. From a control standpoint, some of the peculiarities encountered with analytical instruments include:

- their reliance on samples abstracted from the main stream and carefully conditioned before being presented to the instrument
- the intermittent nature of the data flow from the instrument to the controller



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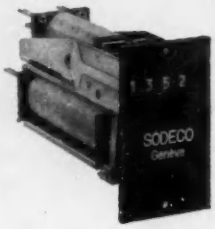

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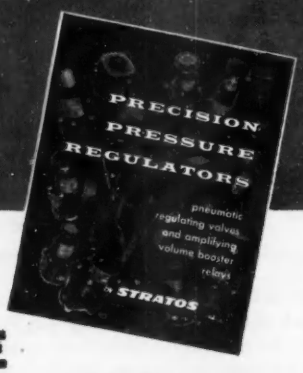

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ABSTRACTS

• the possibility that the chemical composition measured by the instrument may not be a function of one easily-manipulated variable.

One of the existing problems is long transport lag, an inherent feature of control systems that rely on periodic samples. Two convenient measures used to define the effect of this transport lag on the quality of automatic control are the *deviation reduction factor* or DRF—which expresses the power of the controller to reduce the effect of a step disturbance, and the *frequency* of subsiding oscillations that take place after a disturbance. The latter expresses the rapidity with which the controller can reduce the error to zero.

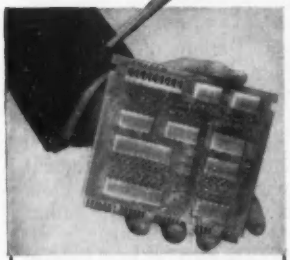
If after everything possible has been done to reduce transport lag or dead-time, the estimated control is still insufficient, two general resorts remain. The first is the independent control of every possible source of disturbance at its origin; possibilities in this direction are very limited. The second involves the use of cascade control, which has many advantages and very often can effect remarkable improvements in system performance.

"Process coupling", or the presence of undesirable interactions between controllers linked only through the process, seldom occurs. However, because both temperature and analysis controls tend to be dynamically slow, there is a certain probability of coupling. This probability can be estimated by simple vector methods.

The most distinguishing feature of sampled-data systems as compared with continuous control systems is their open-loop operation. Anything that happens in the process between data samples is not discovered and cannot be corrected for until the next sampling instant. Thus performance is strongly influenced by the sampling period, and when this period becomes very much smaller than the plant lags, the system tends to behave as though data were available continuously to the controller.

To study the dynamic characteristics of cascade or sample-data systems, frequency response analysis has no rival for convenience, accuracy, low cost, and freedom from interference with the process. Correlation analysis can be used when, for one reason or another, frequency response techniques are ruled out. In this case, however, the analysis is costly and accuracy not too high.

Transac miniature computer . . .



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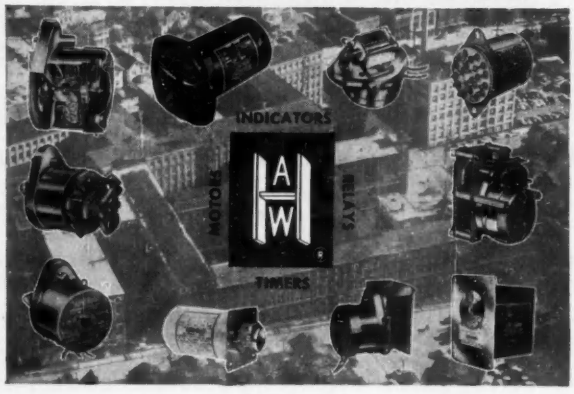

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NEW BOOKS

Primer for Control

BASIC AUTOMATIC CONTROL THEORY. *Gordon J. Murphy, assistant professor of EE, University of Minnesota. 557 pp. Published by D. Van Nostrand Co., Inc. Princeton, N. J., 1957. $9.00.*

Here in this single-volume textbook of control basics is all the theory required for the analysis and synthesis of linear control systems. For simplicity, only those systems are considered that have fixed, lumped parameters, and are subject to easily specified input commands and disturbances. According to the author, the book evolved from lecture notes he used in teaching a course in control theory to seniors and first-year graduate students in engineering and physics at the University of Minnesota. It should prove an excellent choice as a text in similar college courses.

The first three chapters familiarize the reader with types of control systems, terminology peculiar to the field, physical analogies involved, and the characteristics of common system components. Chapter 4 and Appendices I and II provide the necessary mathematical background for understanding the work that follows. Chapter 4 introduces the theory of the Laplace transformation by comparing it with the Fourier series and with the Fourier integral; Appendix I shows a number of methods for finding the approximate roots of characteristic equations, and Appendix II presents the elementary complex variable theory.

A generalized transfer-function concept is developed in Chapter 5, which also contains sections on the use of block diagrams and signal flow graphs. Chapter 6 outlines two methods for classifying control systems, and serves to reveal the similarity of chemical process control systems to instrument servos, navigational computers, and other types of systems. As the author points out, ". . . the principles involved in the chemical process control systems are the same as those in the other systems; *only* the terminology is different."

Stability, ultimate-state response, and transient response of multiloop systems are treated next. Chapters 8, 9, and 10 deal with frequency-response techniques, time-response techniques, and a correlation of these methods, showing the advantages and disadvantages of each. The last chapter covers analog computers and their applica-

". . theory is fine . . . but:

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. . . a paired trigger generator with fixed and delayed pulses. Combination of counters and digital dial provides direct reading delay to 9,999.99 microseconds accurate to better than 0.01 microsecond. Note that this instrument is a full size module of the TLI Modular Instrumentation System.

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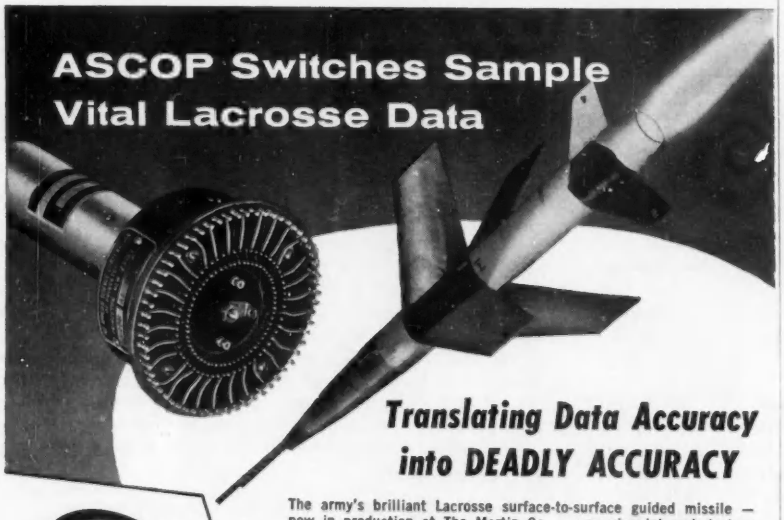

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tions, using as illustrations systems discussed in earlier chapters.

Problems at the end of each chapter are carefully selected to apply to the theory discussed. There are over 250 such problems and many illustrative examples.

Besides appearing to be an excellent college text, the book should also appeal to the many engineers and scientists who, for one reason or another, would like to broaden their knowledge of control theory.

A Text for Product Design

DESIGNING FOR PRODUCTION. *E. N. Baldwin and B. N. Niebel, 645 pp. Published by Richard D. Irwin, Inc., Homewood, Ill.* $8.40.

This book was written for engineering students who expect to associate themselves with product or process design, particularly in the metalworking or electrical manufacturing industry. It opens with a brief discussion of some of the general considerations in product design: the qualifications and opportunities for product design engineers, sales considerations (such as product appearance and surface treatment), and economic considerations (estimating product costs, cost procedures, cost reduction activities and development costs).

The bulk is then devoted to a detailed description of 1) materials frequently used in product design, and 2) processes. In the chapter on ferrous metals, the authors cover the gamut, from cast iron to special kinds of steels, including a considerable amount of tabulated data. Typical tables: properties of rust-resistant steel, minimum properties of carbon steel bar, strength-weight factors, machineability ratings and tolerances of hot- and cold-rolled steel sheet. Similar treatment is given to nonferrous metals, with an emphasis on aluminum and its properties, copper and copper base alloys, nickel and nickel alloys, and low temperature alloys.

The chapter on plastics describes in detail not only the properties of different kinds of plastics, but good and bad design techniques with these nonmetallic materials. Still another chapter covers the use of natural and synthetic rubbers in design applications. There is one catch-all chapter that includes discussions of the properties of materials less frequently used in product design: ceramics, wood, carbon, and glass.

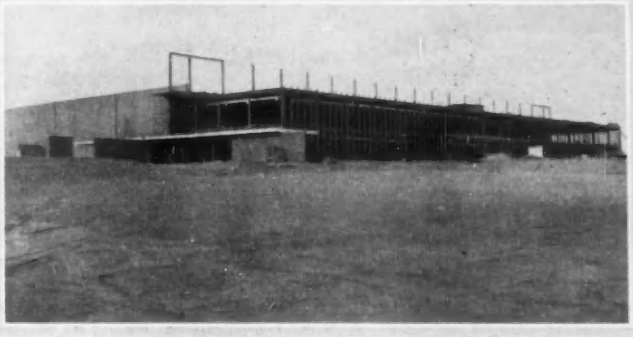
The chapters on processes indicate

30-channel, analog-digital converter connecting 300-amplifier analog computer to 1103A digital computer

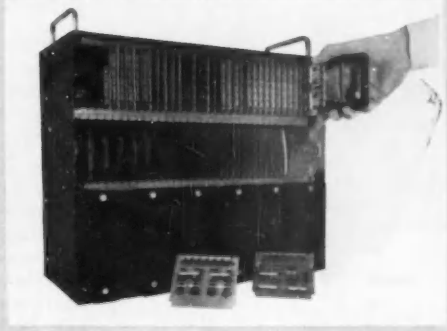
Production of communications equipment in new Los Angeles manufacturing plant

Data Reduction Center designed and built by Ramo-Wooldridge

One of three new research and development buildings completed this year



First unit of Denver manufacturing plant now nearing completion



Input-output unit of the Ramo-Wooldridge RW-30 airborne digital computer

Pictorial **PROGRESS REPORT**

The photographs above illustrate some of the recent developments at Ramo-Wooldridge, both in facilities and in products. Work is in progress on a wide variety of projects, and positions are available for scientists and engineers in the following fields of current activity:

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- Digital Computers and Control Systems
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the importance the authors attach to this phase of product design. One chapter is devoted entirely to casting and molding techniques. Another chapter covers the hot working of metal—pressing and forging techniques. A third chapter discusses cold working techniques, shearing, drawing, extruding, and bending processes. Use of machine tools are discussed in two chapters. One covers theory while the second describes practical material removal processes. The essential role played in production by joining processes is the subject of another chapter in which the authors concentrate on various kinds of welding and fasteners such as nuts, bolts and screws.

There are other chapters to cover assembly operations, finishing, and heat treating. The final section of the book includes miscellaneous information that a product designer should have available: a chapter on quality control, one on packaging, and another on patents. There is also included a brief discussion of automation, defined as "increased mechanization".

Plant Design

PROJECT ENGINEERING OF PROCESS PLANTS. *H. F. Rase and M. H. Barrow.* 692 *pp. Published by John Wiley & Sons, Inc., New York.* $14.25.

This book covers project organization, planning, and execution techniques in large process-plant engineering construction. It is written from the viewpoint of the project engineer by authors who have had considerable experience in plant design supervision with both operating companies and engineering-construction firms. The book's treatment of the broad areas of plant location and process design, procedures and procurement practices, business and legal phases, equipment specification and design, piping, instruments, insulation, structural and foundation work, and field construction practices make it useful as a college text on chemical engineering plant design. The selection of references at the end of each chapter emphasizes catalogs, handbooks, design manuals, codes and standards, trade association publications, and other practical sources. This lends a great deal of value to the book as a working reference for the practicing engineer.

For those who specialize in process-plant instrumentation, the book can be a useful guide to a broader under-

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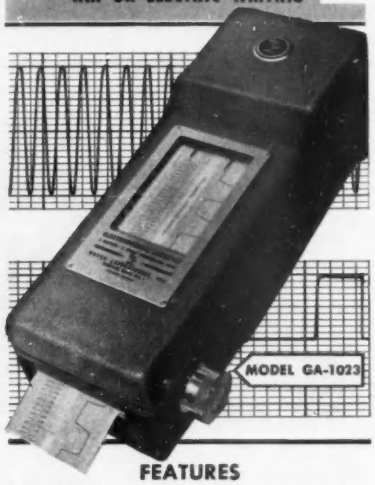

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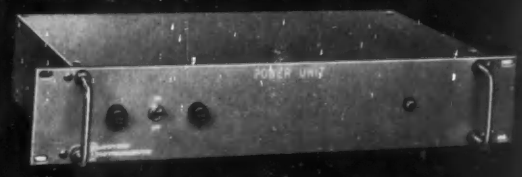

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standing of the various phases of work which are necessary for the design and construction of a modern plant. All too often the educational background of the instrument specialist does not encompass the vast areas of chemical engineering, business administration, and other fields in which he must have sufficient knowledge to relate his activities to other departments within his organization. While the prime responsibility for coordination lies with the project engineer, it is becoming increasingly necessary for instrumentation specialists and particularly instrument department heads to anticipate the routine problems which arise from process and engineering procedural requirements. The authors point out that successful instrumentation demands close cooperation between process, project, and instrument engineers, and a mutual understanding of each other's fields, as well as an appreciation of new techniques and developments in their own fields which continue at a bewildering rate.

The book is a record of information and techniques used in plant design and a discussion of ideas that many project engineers have developed through years of practice. Similar records prepared by project engineers having varying backgrounds in operating and engineering-contracting companies will add to the stature of the profession.

Urie Yarden

How to Up Production

PRACTICAL AUTOMATION. *Lester R. Bittel, Morley G. Melden, & Robert S. Rice, Associate Editors, "Factory Management & Maintenance." 376 pp. Published by McGraw-Hill Book Co., Inc., 1957. $7.50.*

This illustrated guidebook shows plant management how to install and use automation to increase productivity, lower operating costs, and improve safety and working conditions. Throughout the book, the word automation is used in the broadest sense. As the authors state ". . . practical automation includes technological developments that increase industrial productivity—regardless of the form they take. We do not require the criterion of 'feedback' control."

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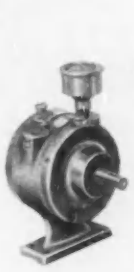
specifications

model no.	output at 60 psi air pressure	net wt
1AM	0.11 hp @ 2,000 rpm 0.21 hp @ 5,000 rpm	1½ lb
2AM	0.13 hp @ 500 rpm 0.3 hp @ 1,500 rpm	5¼ lb
4AM	0.27 hp @ 500 rpm 0.67 hp @ 1,500 rpm	7½ lb
6AM	0.4 hp @ 500 rpm 1.1 hp @ 1,500 rpm	17 lb
8AM	1.0 hp @ 500 rpm 2.5 hp @ 1,500 rpm	25 lb



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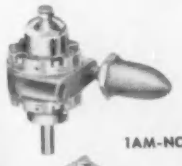

1AM-NCC-11

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5 TYPES, 16 SIZES—TO 30 PSI

Integral (motor-pump)—Compact, light weight, efficient "package" units. Vanes take up their own wear. Compressor rotor mounted on motor shaft for quiet, pulseless air delivery.

Light-Duty — For intermittent service. Quick pick-up, positive displacement. Resemble heavy-duty models but without fans or deep cooling fins, not needed for brief operating periods. Simpler lubricator. (Not illustrated)

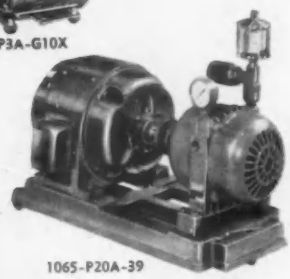
Heavy-Duty—Fan-cooled—For long, continuous operation. Rotary design gives more air per lb., per hp. Automatic lubricator has self shut-off.

specifications

model	model no.	cfm	rec. max. pressure psi: continuously	rec. max. pressure psi: 10 minutes on-off	hp	net wt*
Integral (motor-compressor)	0406	0.6	15	20	1/12	16 lb
	0211	1.3	15	25	1/6	22 lb
	0321	2.2	20	25	¼	25 lb
	0521	3.8	15	20	⅓	26 lb
light-duty	0240	2.0	10	20	¼	8 lb
	0440	3.8	10	20	⅓	10 lb
	0740	5.6	7	10	⅓	11 lb
heavy-duty fan-cooled	0465	3.8	25	30	½	18 lb
	0765	5.6	10	15	½	18 lb
	1065	8.3	25	30	1	34 lb
	2065	17.0	15	20	1½	54 lb
	2565	21.0	15	20	2	54 lb
	4565	45.0	20	20	5	92 lb

*Weight without base or motor, except integral models.

0211-P3A-G10X



1065-P20A-39

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Integral (motor-pump) — Compact, light weight, "packaged" units. Save mounting cost and time. Especially suited for portable equipment. Rotor mounted on motor shaft. Rotary design gives quiet operation, pulseless vacuum. Vanes take up own wear.

Light-Duty — For intermittent service. Give quick pick-up, trouble-free performance. Resembles heavy-duty models but without external fans or deep cooling fins. Simpler lubricator. (Not illustrated)

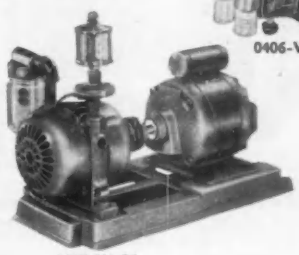
Heavy-Duty-Fan-Cooled — Built for continuous service, dependability, minimum maintenance. Forced air cooling, deep cooling fins. Automatic lubricator has self shut-off.

specifications

model	model no.	cfm	rec. max. vacuum, in hg.: continuously	rec. max. vacuum, in hg.: 10 minutes on-off	hp	net wt*
Integral (motor-pump)	0406	0.6	15	25	1/12	16 lb
	0211	1.3	15	27	1/6	22 lb
	0321	2.2	28		¼	27 lb
	0521	3.8	28	—	⅓	28 lb
light-duty	0240	2.0	15	26	¼	9 lb
	0440	3.8	15	26	¼	11 lb
	0740	5.6	10	26	⅓	12 lb
heavy-duty fan-cooled	0465	3.8	26		¼	18 lb
	0765	5.6	28		⅓	18 lb
	1065	8.3	28		½	34 lb
	2065	17.0	28		1	54 lb
	2565	21.0	28		1½	54 lb
	4565	45.0	20	28	3	92 lb

*Weight without base or motor, except integral models.

0406-V-2-154X



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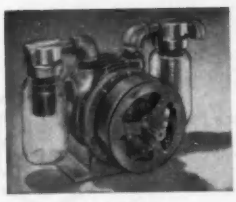

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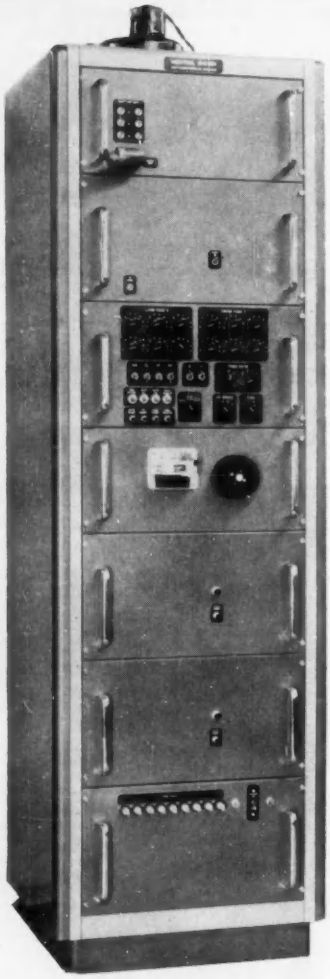

Wang Laboratories, Inc. has developed a new contour control system for machine tool operation. This is a self-programmed, numerically controlled system, operating directly from paper tape or punched card.

For more details write Dept. C-9.

Illustration shows a Weditrol system designed for high-speed production lathes.

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NEW BOOKS

and full-scale automation, and the application of each to the job shop and small plants.

Section II covers automation in the various manufacturing processes. Materials handling, inspection, and assembly are also shown to be susceptible to different degrees of automation. Other sections of the book get into plant engineering and maintenance for automation, and other problems that accompany the advent of automation in a plant.

For Reference

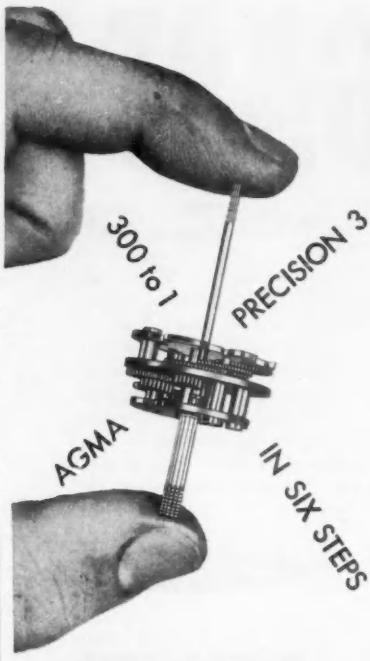
STANDARD HANDBOOK FOR ELECTRICAL ENGINEERS. *9th edition prepared by a staff of specialists under the editorship of Archer E. Knowlton, consulting editor,* Electrical World. 2311 *pp., illustrated.* McGraw *Hill Book Co., Inc., New York.* $19.50.

This well-known reference book has been considerably revised and updated in its ninth edition, which represents an attempt by the authors to incorporate all the latest developments in the electrical art.

New or extended material has found its way into every section. The conductor tables (Section 4) have been completely recomputed to conform to the latest ASTM standards. Material on the electrical measurement of nonelectrical properties has been expanded because of its value today in the field of industrial automation. The addition of new telemetering methods, plus other changes, make the measurements section considerably more useful to both users and manufacturer of electrical instruments. Magnetic amplifiers are also treated more extensively in conjunction with control.

Transistors, which have really come of age since the eighth edition, are treated quite extensively in Section 23 (some 14 pages are used to cover semiconductor theory and application). Sections on illumination, power transmission, and electricity in transportation have also been greatly modified.

In spite of the sizable additions mentioned above, the editor and the authors have maintained the overall size of the volume within tolerable limits. This has been accomplished by eliminating much of the material which pertained to now obsolescent practices.



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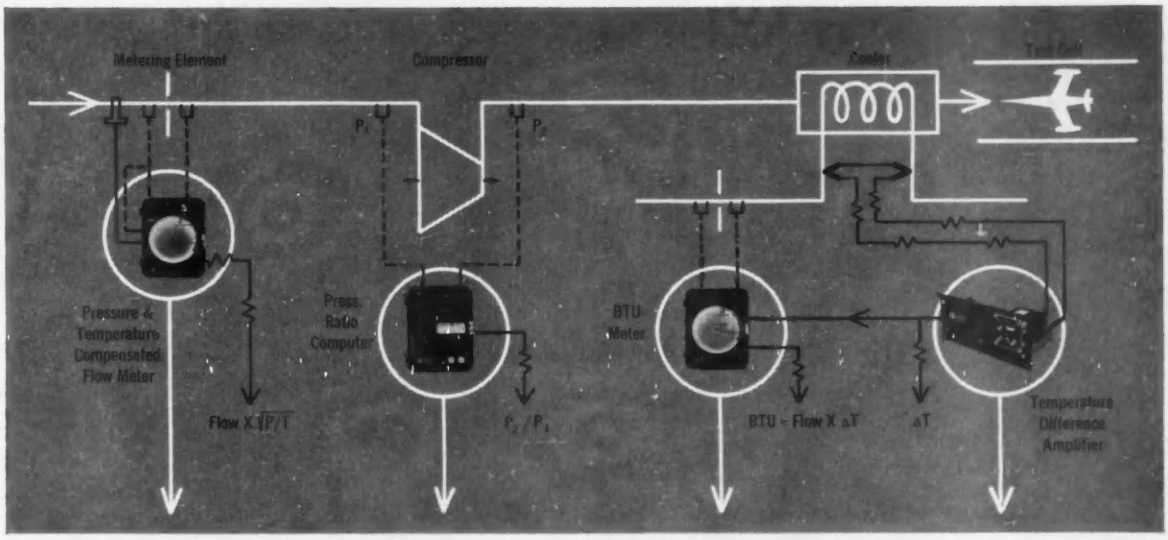

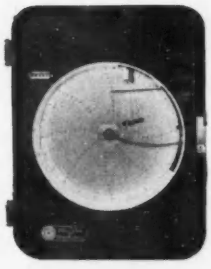

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Ask for Bulletin MSP 141.

PR-O Pressure Ratio Computer
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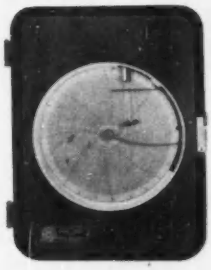
Ask for Bulletin MSP 103B.



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Here, the standard Ring Balance meter is teamed with a Hagan PowrAmp Model "P" dc amplifier to produce an accurate measurement and record of liquid flow, temperature difference and heat removal by a cooler. This device computes the product of liquid flow times temperature difference. Temperature differences as low as 10°F, full scale, can be measured and converted into motion by the Model "P" amplifier and associated servo-motor system.
Ask for Bulletin MSA 107A.

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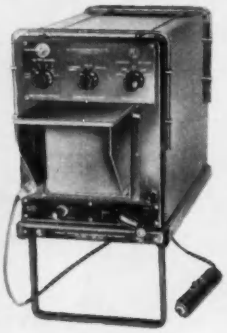

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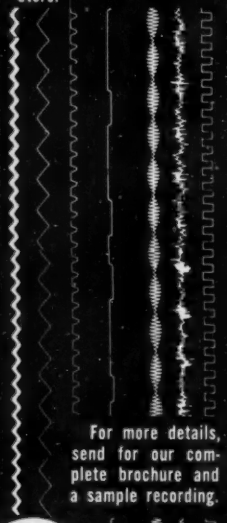

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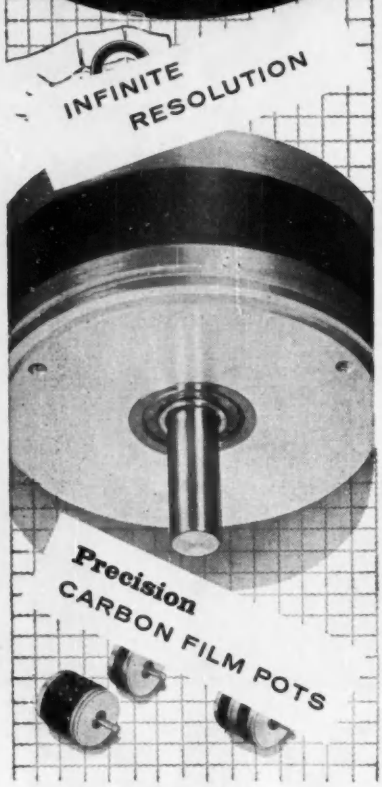

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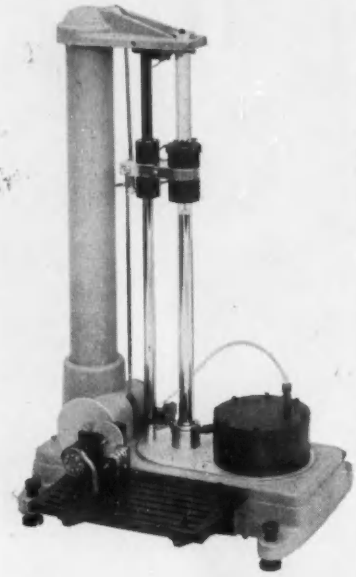

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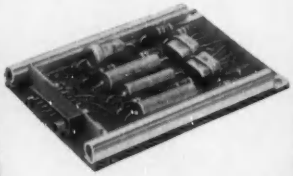

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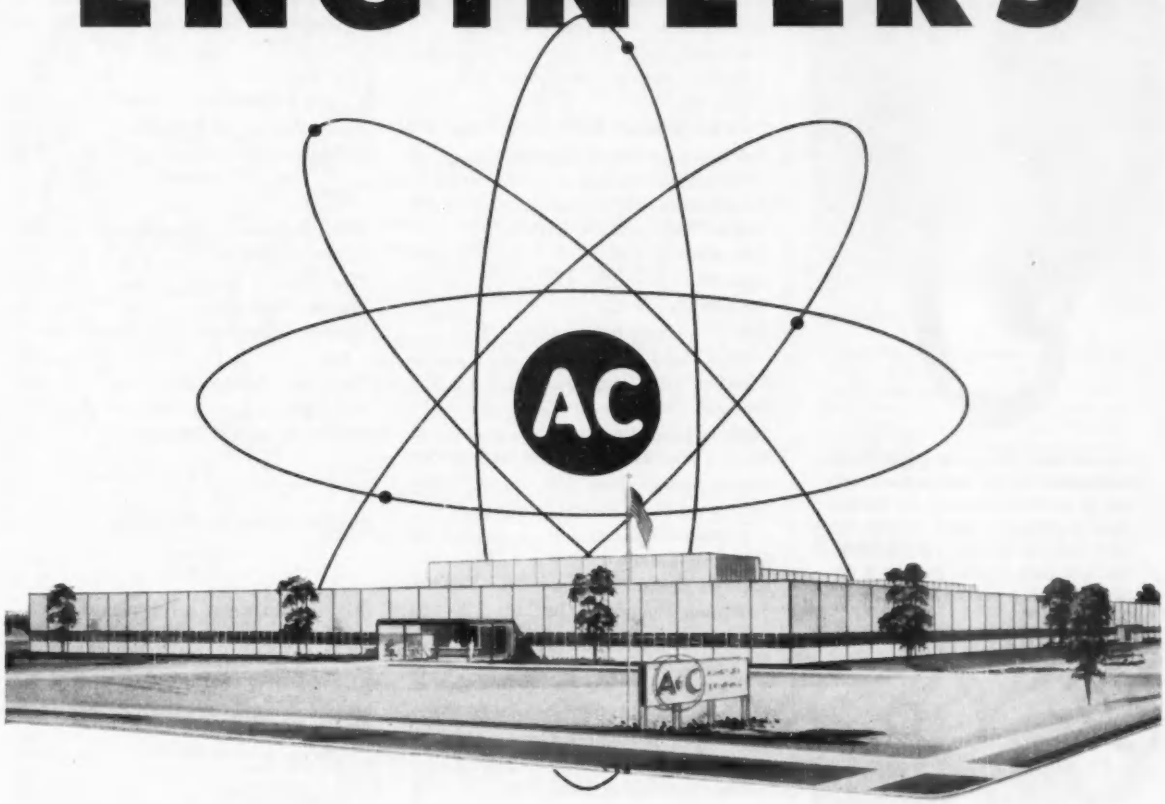

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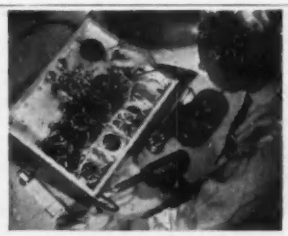

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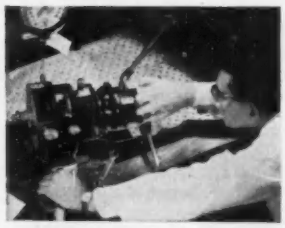

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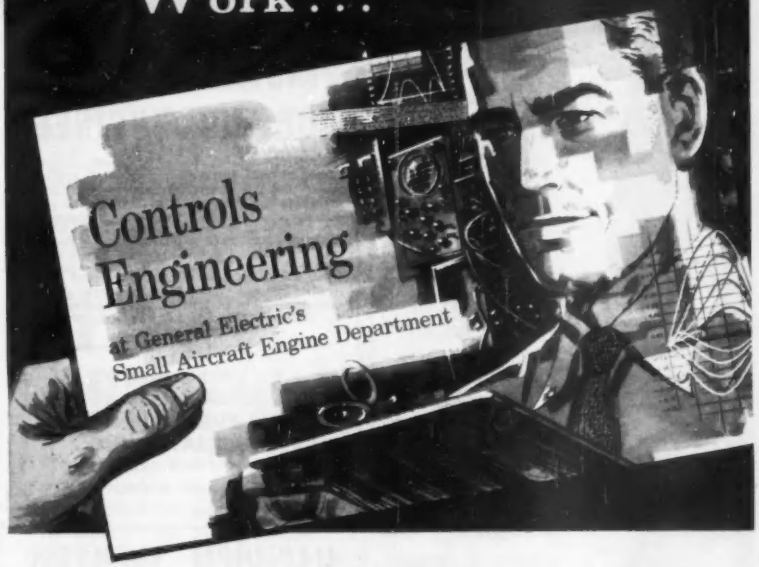

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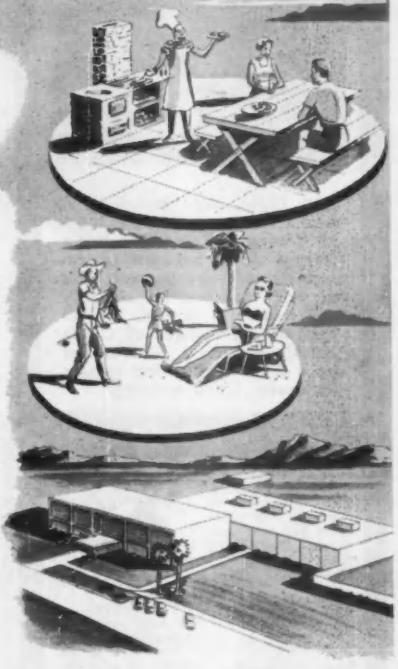

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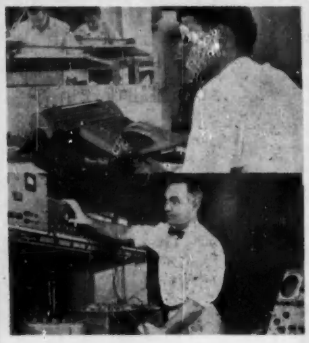

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WHAT'S AHEAD: MEETINGS

AUGUST

American Institute of Electrical Engineers, Pacific General Meeting, Pasco High School, Pasco, Wash. Aug. 26-30

Instrument Society of America, First International Symposium on Gas Chromatography, Michigan State University, Kellogg Center, East Lansing, Mich. Aug. 28-30

SEPTEMBER

Institute of Radio Engineers, PGIE, 2nd Special Technical Conference on Magnetic Amplifiers, Hotel Penn Sheraton, Pittsburgh. Sept. 4-6

Instrument Society of America, 12th Annual International Conference and Exhibit, Cleveland Auditorium, Cleveland, Ohio Sept. 9-13

Institute of Radio Engineers, Symposium on Industrial Electronics, (transducers, components, and systems for electronic control), Morrison Hotel, Chicago Sept. 24-25

OCTOBER

National Electronics Conference, 13th Annual, Hotel Sherman, Chicago Oct. 7-9

American Institute of Electrical Engineers, Fall General Meeting, Hotel Morrison, Chicago Oct. 7-11

American Institute of Electrical Engineers, Feedback Control Systems Committee, "Computers in Control Symposium", co-sponsored by IRE, Professional Group on Automatic Control, and ASME-IRD, Chalfonte-Haddon Hall Hotel, Atlantic City, N. J. Oct. 16-18

Institute of Radio Engineers, Canadian Convention, Exhibition Park, Toronto, Can. Oct. 16-18

National Conference on Industrial Hydraulics, sponsored by Armour Research Foundation and Illinois Institute of Technology, Hotel Sherman, Chicago Oct. 17-18

Computer Application Symposium, sponsored by Armour Research Foundation, (registration fee of $35 includes luncheons), Hotel Sherman, Chicago Oct. 24-25

Institute of Radio Engineers, East Coast Aeronautical and Navigational Conference, Lord Baltimore Hotel and 7th Regiment Armory, Baltimore, Md. Oct. 28-30

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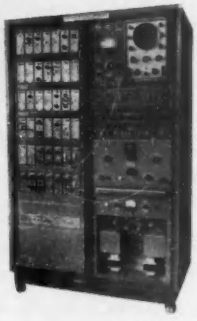

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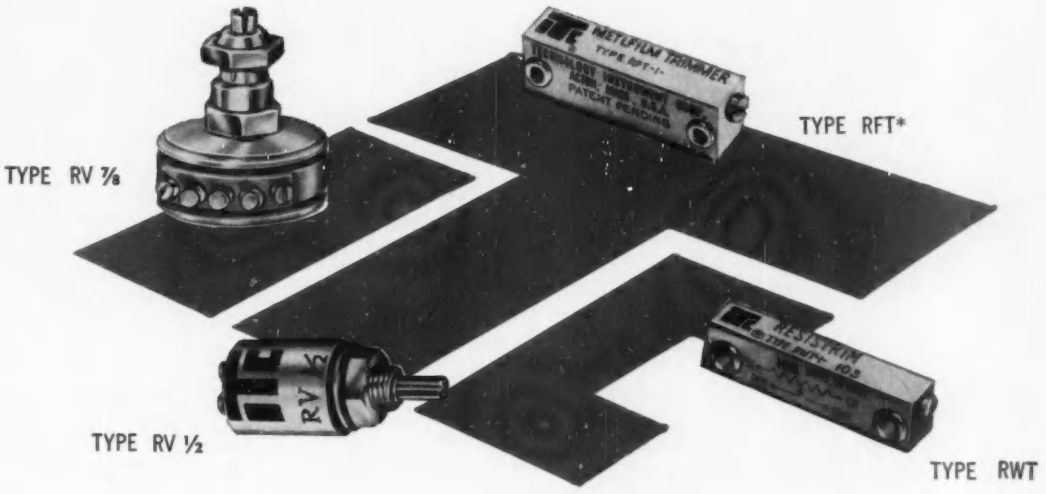

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RWT	25 wire wound	50 to 15K ohms	—55° to +95°C
RV ½	1 wire wound	50 to 100K ohms	—55° to +145°C
RV ⅞	1 wire wound	100 to 100K ohms	—55° to +145°C

* Optimum spacing — as many as 7 in area of 1 sq. in.
All designed for the most stringent aircraft and rocket applications.

All units are available from stock in production quantities.

Complete information on request.

These advanced design features provide for wide applications:

- ►Threshold voltage adjustment
- ►Fixed gain adjustment
- ►Parameter compensation
- ►Critical magnetic and electric bias
- ►Establishing circuit values
- ►Padding
- ►Balancing adjustments
- ►Adjusting scale factors

TECHNOLOGY INSTRUMENT CORP.

523 Main Street, Acton, Mass. COlonial 3-7711

WHAT TO SEE AT ISA

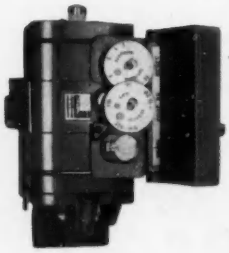
new products
new ideas
new applications

- *new magnetic flowmeter*

Obstructionless, trouble-free! the big attractions of F & P's new magnetic flowmeter. This highly accurate flowmeter requires no long metering runs, has no line obstructions, causes no pressure drop . . . and measures fluid velocity directly! Ideal for metering and blending a variety of fluids, paper pulp, slurries, and corrosive liquids.

- *new series of corrosion-proof instruments*

Housed in reinforced fiber glass cases, F & P's new line of small indicators, transmitters, and controllers are as corrosion resistant as the equipment they control! The fiber glass case and all exposed fittings resist the deteriorating effects of acids, alkalis, salts, solvents, dust, and weather.



- *new improved pneumatic controller*

Balance-type pneumatic controller has outstanding static and dynamic performance characteristics. New features include non-bleed type amplifying relay of increased capacity, yet reduced steady-state air consumption, plus a marked increase in the gain of the error detection circuit through a "regenerative" feedback system. This improves linearity and increases nozzle flapper clearance, reducing flapper motion requirements.

*

- *new differential pressure transmitter*

This force-balance differential pressure transmitter features adjustable internal damping. Transmitter range is adjustable from 0-20 to 0-200 inches of water at static pressures up to 1500 psi. Unique design provides complete overrange protection and excellent temperature and static pressure stability. The entire unit is free from pipe strain effects. Wetted parts can be supplied in a variety of materials.

- *automatic data logger*

Modular construction of this F & P new Series 1200 scanner-logger assures flexibility and adaptability to process change and expansion. Series 1200 accepts any combination of up to 200 inputs, scans and compares them against set limits at 5 points per second, and periodically logs all points at 1 point per second.

*

For more information on the products shown above, write to Fischer & Porter Company, 797 County Line Road, Hatboro, Pa. In Canada, write Fischer & Porter (Canada) Ltd., 2700 Jane Street, Toronto, Ontario.

* See full page advertisements shown elsewhere in this magazine.

SEE YOU AT BOOTH 1344

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Complete Process Instrumentation